1967

The surface morphology of a small drainage basin in the North Dakota Badlands

J. Ladd Hagmaier
University of North Dakota

Recommended Citation

Hagmaier, J. Ladd, "The surface morphology of a small drainage basin in the North Dakota Badlands" (1967). *Theses and Dissertations*. 114.
https://commons.und.edu/theses/114

THE SURFACE MORPHOLOGY OF A SMALL DRAINAGE BASIN IN THE NORTH DAKOTA BADLANDS

by

Jonathan L. Hagmaier

B. S. in Earth Science, Eastern Kentucky University, 1966

A Thesis
Submitted to the Faculty
of the
Graduate School
of the
University of North Dakota
in partial fulfillment of the requirements
for the Degree of
Master of Science

Grand Forks, North Dakota

August
1967

This thesis submitted by Jonathan L. Hagmaier in partial fulfillment of the requirements for the Degree of Master of Science in the University of North Dakota is hereby approved by the Committee under whom the work has been done.

Duane L. Younggren
Chairman

John C. Hudson

Lee Clayton

A William Johnson
Dean of the Graduate School

ACKNOWLEDGEMENTS

The writer would like to express his appreciation to Professor Duane L. Younggren, Chairman, Department of Geography, Dr. John C. Hudson, Department of Geography, and Dr. Lee Clayton, Department of Geology, for their valuable criticism and advice during the preparation of the manuscript and for their service as members on the examining committee.

The writer also wishes to thank Mr. Arthur L. Sullivan, Superintendent, Theodore Roosevelt National Memorial Park, and the many park officials for their cooperation and assistance during the field work for this study, and the National Science Foundation whose financial support made the graduate work and field research possible.

A special thanks is in order to the author's wife, Peggy, for her interest and long hours of typing in the preparation of this thesis.

TABLE OF CONTENTS

TABLE OF CONTENTS Continued

LIST OF TABLES

LIST OF ILLUSTRATIONS

ABSTRACT

To describe the surface morphology of a fourth order drainage basin located in the North Dakota Badlands, the writer made quantitative applications of known descriptive techniques and morphological laws.

The surface configuration is a function of the study area's linear, areal, and relief properties and surface elements. The linear and areal properties are determined from maps showing the drainage basin's surface geometry, the relief properties are determined from large-scale topographic maps of the area, and the surface elements are determined by direct field measurements of the ground slopes, surface materials, and vegetal coverage.

The surface geometry of the drainage basin is expressed by the relationship between the number of streams, stream lengths, basin areas, and stream order numbers; while, the characteristics of its erosional topography are defined by the elongation ratio, constant of channel maintenance, texture ratio, drainage density, stream frequency values, and a hypsometric analysis. Maps of the surface elements and their associated frequency distributions represent the areal location and relative magnitude of the different classes composing each component of the surface elements.

The descriptive forms representing the study area are analogous to many of those revealed in comparative studies of other badland areas; however, some of the study area's topographic aspects appear to be unique to the North Dakota region.

CHAPTER I

INTRODUCTION

Purpose

This paper presents a systematic description of the surface morphology of a small drainage basin in the North Dakota Badlands. The land surface configuration is resolved into its component parts so that a complete description of its properties can be characterized in specific terms element by element; hence, an attempt is made to synthesize the planimetric raw landscape into a significant series of functional interlinkages which will effectively benefit both the pure and the applied aspects of geomorphology.

The emphasis of the study is upon the dimensions and arrangements of surface patterns, slopes, and surface materials rather than upon the dynamic processes of erosion and transportation which shaped the land forms. Erosional processes are, however, considered to a limited extent in coordination with discussions on certain aspects of surface morphology.

Location and Description of Study Area

The study area is located in the South Unit of the Theodore Roosevelt National Memorial Park, Billings County, North Dakota, (Figure 1).[1] It is a tributary basin to Jones Creek. Jones Creek flows through the central part of the park approximately 10 miles north

---

[1] A point near the center of the drainage basin is located 46° 57' 40" North Latitude, 103° 28' 20.4" West Longitude.

LOCATION OF STUDY AREA

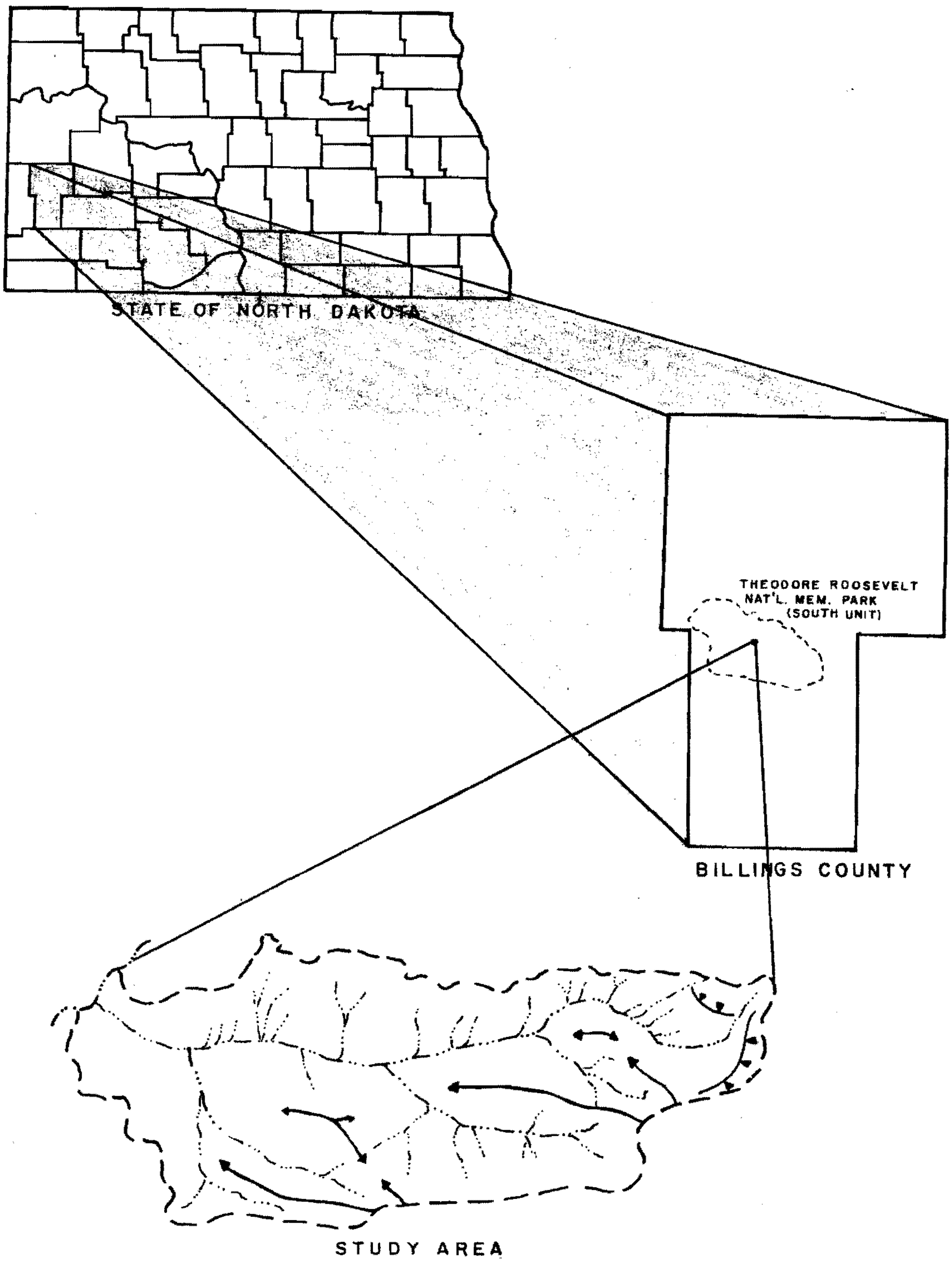


Fig. 1.

of Medora, North Dakota, and empties into the Little Missouri River. The longitudinal orientation of the drainage basin is in a southwest to northwesterly direction. The east-west trend of the major drainage channels thus causes a pronounced effect of microclimatic environments. These effects are evidenced by the difference in vegetation, slopes, and surface materials present on opposing north and south facing slopes.

The area was chosen for study because the badland topography of North Dakota contains well-developed drainage basins in homogenous lithology, structure, and climate which are small enough to be surveyed, mapped, and studied in detail. The Badlands of North Dakota are composed of Paleocene-age rocks which are primarily poorly cemented sands, clays, and siltstones.[2] These materials have been extensively eroded into buttes and gullies; largely by the work of running water aided by other natural agents such as mass movements, wind and burning lignite. Burning lignite beds have baked and fused overlying sands, shales, and clays causing a hardening of the material into clinker beds (locally called "scoria beds"). Clinker beds are resistant to erosion and thus form caps for the development of buttes and other high areas.[3]

The drainage basin covers an area of 0.15 square miles. It contains four major intrabasin ridge crests, all capped by clinker beds. The ridge crests in turn cause four major bifurcations in the drainage system of the basin. The drainage channels of the basin are entirely ephemeral and numerous in number, ranging from miniature finger-tip rills to large gullies having 6 to 10 feet high nickpoints near the

---

[2] Wilson M. Laird, The Geology of the South Unit Theodore Roosevelt National Memorial Park (Grand Forks: North Dakota Geological Survey, Bulletin 25, 1950), p. 13.

[3] Ibid.

mouth of the basin. An idea of the actual appearance of the drainage basin may be gained from Figures 2 and 3.

Previous Geomorphic Studies Done in Area

Little geomorphic work has been done in the Badland area of North Dakota. Laird, Chairman, Department of Geology, University of North Dakota, gave a general description of the physiography and topographic appearance of the area in 1950 when he published a bulletin entitled The Geology of the South Unit Theodore Roosevelt National Memorial Park.[4] Hamilton, a graduate student in geology at the University of North Dakota, did thesis research in the area in 1966.[5] His study was primarily concerned with the dynamic processes involved in the fluvial erosion of gullies in the western North Dakota area. Most of the work Hamilton did in the park was in the Jones Creek area. The United States Geological Survey is presently compiling and printing large-scale 7.5 minute topographic maps of the area.

Schumm did a geomorphic study similar to this one on a small badland area at Perth Amboy, New Jersey.[6] His study was concerned with both surface morphology and erosional processes; however, the emphasis of his study was on erosional processes. Nevertheless, his report contains valuable information which can be used as a comparison with the results of this study.

---

[4] Ibid., pp. 1-18.

[5] Thomas M. Hamilton, "Recent Fluvial Geology in Western North Dakota" (unpublished Master's thesis, University of North Dakota, 1967).

[6] Stanley A. Schumm, Evolution of Drainage Systems and Slopes in Badlands at Perth Amboy, New Jersey (Bulletin Geological Society of America, Volume 67, May, 1956), pp. 597-646.

Fig. 2--Airphoto stereo pair of study area.

Fig. 3--Ground view of drainage basin looking toward basin terminus.

Climate of the Study Area

The study area has a semi-arid climate (BSk Köppen) which is typical of middle latitude steppe lands having limited precipitation and at least one month with an average temperature below 32°F. The closest meteorological station is at Medora, North Dakota, approximately 10 miles south of the study area. The climatic data used in this paper were compiled from a 30 year period (1930 to 1960) of that station's records.

Most of the area's precipitation falls during the summer months, which is also the period of maximum evapo-transpiration. The precipitation can vary a great deal from year to year; hence, it, along with other climatic factors, can spell abundance or disaster for the vegetation and wildlife of the area. The average annual precipitation in the area is 13.9 inches, 75% of which occurs during the six warm months and 50% during the months of May, June, and July.[7] A precipitation summary of Medora, North Dakota, is presented in Table 1.

The study area has an annual temperature range of approximately 125°F.; the lowest mean monthly temperature (10.6°F.) occurs during January and the highest mean monthly temperature (69°F.) occurs in August. A temperature summary for Medora, North Dakota, is presented in Table 2.

Vegetation of the Study Area

The occurrence of vegetation in the study area is dependent upon the nature of the land surface. Such factors as the degree of soil development, slope exposure, altitude, moisture conditions, and other

---

[7] North Dakota Economic Development Commission, A Combination of Facts About North Dakota, Compiled by David Torkelson (Bismarck: North Dakota Economic Development Commission, 1964), p. 15.

TABLE 1

PRECIPITATION RECORDS FOR MEDORA, NORTH DAKOTA (1930 to 1960)[a]

Month	Rain or Water Equivalent of Snow in Inches			Mean Snowfall in Inches
	Mean	Maximum Recorded	Minimum Recorded	
Jan.	.45	1.98	.04	5.2
Feb.	.50	1.21	.07	5.9
Mar.	.64	1.58	.06	5.1
Apr.	1.02	4.40	.00	2.0
May	1.74	4.14	.58	0.3
Jun.	3.29	7.70	.65	T*
Jul.	1.99	4.37	.18	0
Aug.	1.46	3.81	.26	0
Sep.	1.21	3.47	.00	T*
Oct.	.80	2.35	T*	3.3
Nov.	.56	2.66	T*	3.6
Dec.	.27	1.63	.00	3.1
Yr.	13.93	21.25	10.61	28.6

*Trace of precipitation.

[a] Data from United States Department of Commerce Bulletin Nos. 86-28 and 11-28, Climatography of the United States (Washington: United States Government Printing Office).

TABLE 2

TEMPERATURE RECORDS FOR MEDORA, NORTH DAKOTA (1930 to 1960)[a]

Month	Means in °F.			Extremes in °F.	
	Maximum Daily	Minimum Daily	Monthly Average	Highest Recorded	Lowest Recorded
Jan.	26.7	1.0	10.6	58	-49
Feb.	32.7	5.3	17.9	67	-36
Mar.	39.0	13.7	26.0	77	-33
Apr.	57.5	27.0	42.2	92	- 4
May	70.7	38.8	54.7	94	12
Jun.	77.5	48.5	63.0	100	28
Jul.	86.8	53.5	70.2	109	35
Aug.	86.5	51.7	69.0	110	29
Sep.	74.4	39.7	57.4	105	13
Oct.	62.3	28.2	45.4	95	- 4
Nov.	42.7	16.4	30.3	72	-25
Dec.	34.5	7.7	19.6	59	-38
Yr.	57.6	27.5	42.2	110	-49

[a] Data from United States Department of Commerce Bulletin Nos. 86-28 and 11-28, *Climatography of the United States* (Washington: United States Government Printing Office).

factors too numerous to mention determine the type and density of vegetation located in specific areas within the basin. The most commonly occurring trees and shrubs are the creeping and Rocky Mountain red cedars, sagebrush, and a few species of deciduous trees. The grass types of the area are primarily buffalograss, western bluegrass, and bluebunch wheatgrass.[8]

Basic Investigation Procedures

A morphologic study of the surface geometry and surface elements in a specific drainage basin requires the measurement of its linear properties, areal properties, and relief properties. The first two properties are planimetric, whereas, the third is concerned with vertical inequalities of the drainage basin forms.

An investigation of the linear and areal properties of the drainage basin necessitated the construction of a large-scale map showing the surface geometry of the basin so that planimetric measurements could be made with a reasonable degree of accuracy. The map was made by enlarging 1:7920 scale airphotos of the basin into a 1:2100 scale map of the surface geometry. The map was field checked during the early part of June, 1967, and found to be accurate within 10 feet. A reduced copy of the map is presented in Figure 4.

The Strahler method of stream channel ordering is used in this report for purposes of identifying linear stream measurements with the proper category of channels.[9] A first order stream as it is used in

---

[8] Identification was made in the field with the help of Orin A. Stevens', Handbook of North Dakota Plants (Fargo: North Dakota Institute for Regional Studies, Knight Printing Company, 1950).

[9] Arthur N. Strahler, Hypsometric Analysis of Erosional Topography (Bulletin Geological Society of America, Volume 20, 1952), p. 1120.

SURFACE GEOMETRY

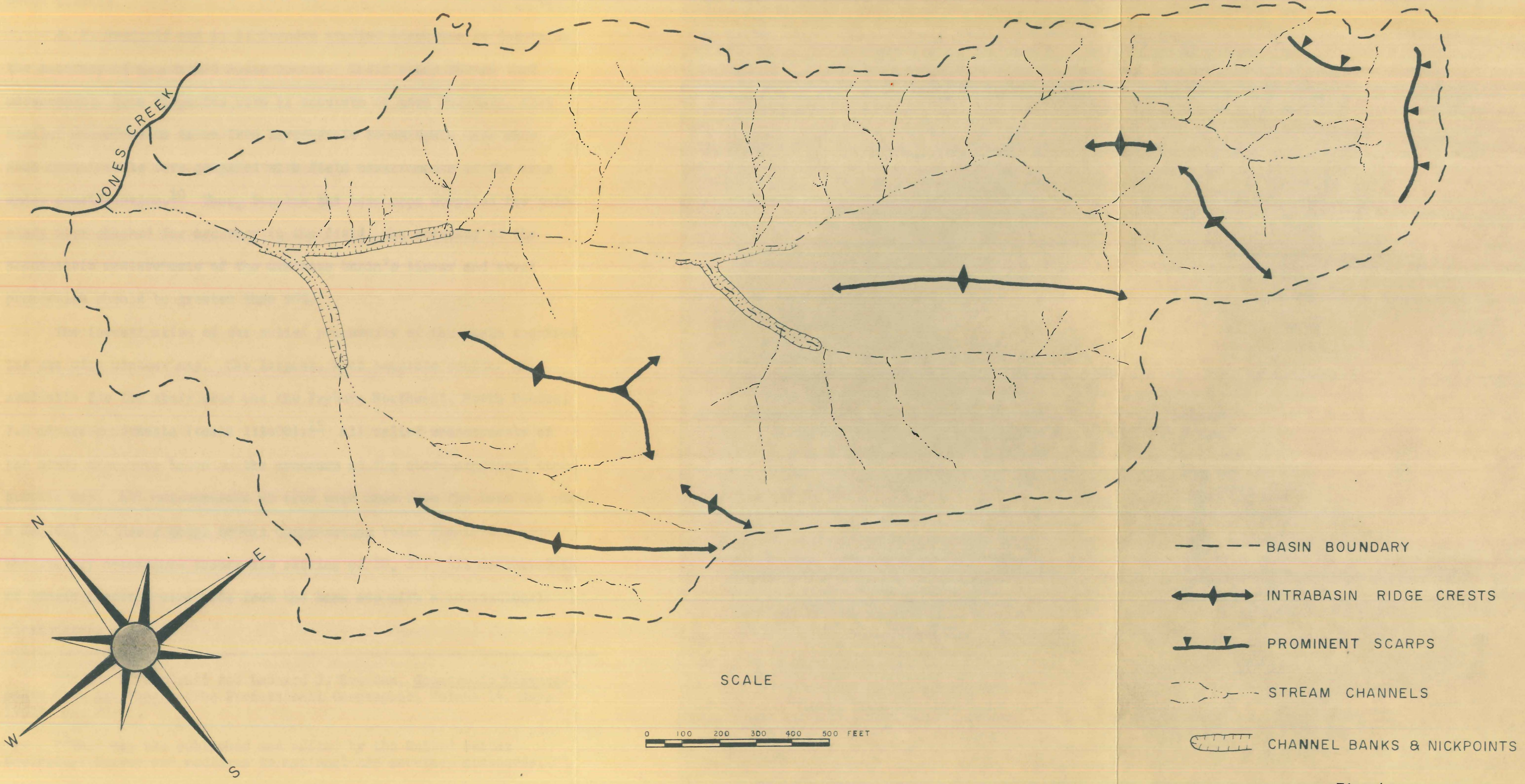


Fig. 4

this study is defined as the most finger-tip channel which can be identified as a stream channel from 1:7920 scale airphotos. The most finger-tip streams, as shown on the base map (Figure 4), are first order streams.

J. F. Woodruff and L. J. Evenden studied airphotos to determine the accuracy of geomorphic measurements. Their study showed that measurements from airphotos were as accurate or more accurate, than similar measurements taken from large-scale topographic maps when such measurements were compared with field measurements of the area under consideration.[10] Thus, because the base maps compiled for this study were checked for accuracy in the field, the accuracy of the planimetric measurements of the drainage basin's linear and areal properties should be greater than 90%.

The investigation of the relief properties of the basin required the use of a contour map. The largest, most accurate contour map available for the study area was the Fryburg Northwest, North Dakota, 7.5 minute quadrangle (scale 1:2400).[11] All relief measurements of the study area were based on the contours of the above mentioned topographic map. All measurements of area were made from the base map with a Keuffel and Esser Model 620015 Compensating Polar Planimeter using the factory determined tracer arm setting of 20, 31. All measurements of linear features were made from the base map with a conventional chartometer.

---

[10] James F. Woodruff and Leonard J. Evenden, Geomorphic Measurements From Air Photos (The Professional Geographer, Volume 14, May, 1962), pp. 23-26.

[11] This map was published and edited by the United States Geological Survey and conforms to national map accuracy standards.

The investigation of surface elements of the drainage basin such as slope angles, vegetal coverage, and surface materials required actual field measurements because such characteristics cannot readily be determined from topographic maps and airphotos. To determine th above characteristics the author spent two weeks in the study area during the early part of June, 1967, taking field measurements. The above characteristics were determined by running a traverse around the basin rim making regular stops every 300 feet and measuring along lines orthogonal to the slope, downward to the stream channel. Measurements were made at regular intervals between 150 and 200 feet apart along the orthogonal lines between the basin rim and stream channel. The interval used depended upon the length of the line between the basin rim and stream channel; when the length was great the larger interval was used and when the length was smaller the lesser interval was used. A minimum of three measurements was made along each orthogonal line. This procedure was followed until the entire drainage basin, including the intrabasin ridges, was covered.

The slope angles were determined with a Brunton compass and a 5 foot long, 2 inch by 4 inch straight edge. The straight edge was laid along the line orthogonal to the slope at each regularly spaced interval or station. The compass was then placed upon the straight edge and the slope of the straight edge itself was read directly as a representation of the slope angle at that point. The primary function of the straight edge was to eliminate micro-topographic irregularities.

The vegetation coverage was estimated at each regularly spaced station along the orthogonal line with the help of the straight edge used in taking the slope readings. The straight edge had lines drawn on it dividing it into quarter sections and was dropped arbitrarily in three places at each station. The vegetal cover was estimated in percentage at each dropping as being equivalent to the percentage of area of the straight edge lying on ground where some type of vegetation (usually grass) was growing. The mean estimation of the three droppings was recorded at each station.

The surface material at each station along the orthogonal line was determined as being either exposed bedrock, poorly developed soil, well-developed soil, or alluvial fill. Exposed bedrock was recorded in areas where bedrock outcrops had little apparent soil cover. Poorly developed soils were recorded when the surface was light in color, the soil shallow in depth, and little if any humus present. Well-developed soils were recorded when the surface was dark and the soil deep with a thick humus layer. Alluvial fill was recorded where the sediment was found to contain abundant clinker, because the only place clinker is found in place in the basin is along the ridge tops. It was often necessary to dig a hole about 1 foot deep to determine what material was present.

CHAPTER II

MORPHOMETRY OF THE STUDY AREA

Linear Properties of the Drainage Basin

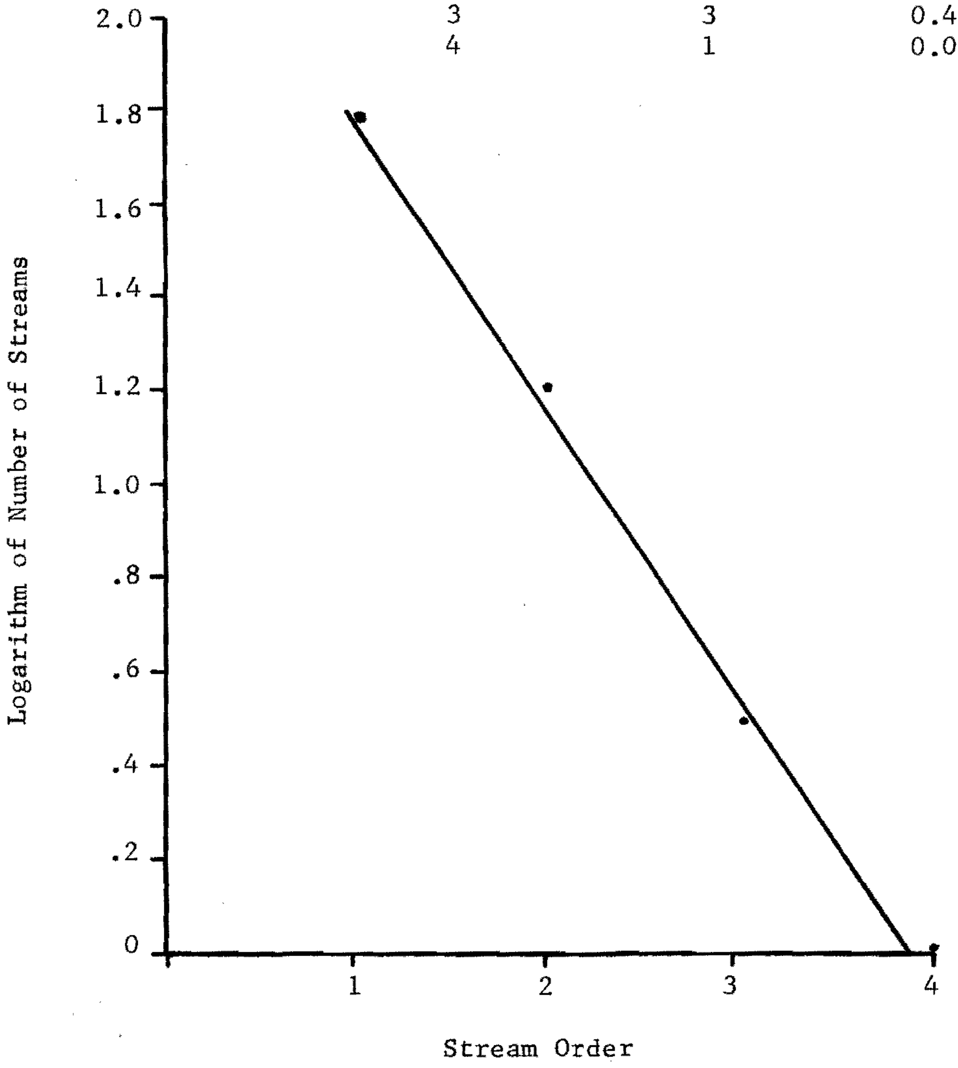
Stream Orders

Certain laws of drainage composition which assume orderly development of the gemetrical qualities of open drainage systems were first introduced into North America by Robert E. Horton. His first law of drainage composition is stated as follows: "The number of streams of different orders in a given drainage basin tend closely to approximate an inverse geometric series in which the first term is unity and the ratio is the bifurcation ratio."[12] When such a geometric sequence exists for a given set of data, the points resulting from a graph of the logarithm of the number of stream segments against their respective stream orders should yield a straight line. Data from the study area were graphed in the above manner. The results may be observed in Figure 5. The graphed data show a noticeable deviation from the regression line near the terminal end of the drainage basin. This indicates that the geometric progression is not closely observed in the higher order stream segments. However, when the graph was compared

---

[12] Robert E. Horton, Erosional Development of Streams and Their Drainage Basins; Hydrophysical Approach to Quantitative Morphology (Bulletin Geological Society of America, Volume 56, 1945), p. 291.

Stream Order	Number of Streams	Logarithm of Number of Streams
1	61	1.79
2	16	1.20
3	3	0.477
4	1	0.000



Regression line equation: $y = 2.396 - 0.612x$

Coefficient of correlation: $r = -0.985$

Fig. 5--Relation of number of streams of each order to order number.

with those from similar studies by Schumm[13] and Strahler[14] the results indicated a general similarity; hence, there is no reason to believe that a basic discontinuity exists in the data representing the study area. Generally, Figure 5 confirms an inverse geometric sequence between stream order and the number of stream segments as suggested by Horton's law.

Bifurcation Ratio

The bifurcation ratio is defined by Strahler as the number of stream segments of a given order to the number of segments contained in the next higher order.[15] For example, a basin containing five second-order streams and 20 first-order streams would have a bifurcation ratio value of 4. The bifurcation ratio is not always the same between different orders because of chance variations in the basin geometry. It does, however, tend to become a constant throughout a series of consecutive stream orders within a given drainage basin.

The bifurcation ratio between any two stream orders has little meaning by itself; hence, the weighted-mean bifurcation ratio was calculated for the study area in accordance with a method used by Schumm. He obtained the weighted-mean bifurcation ratio by multiplying the bifurcation ratio for each successive pair of stream orders in a drainage basin by the total number of streams involved in the ratio and taking the mean of the sum of the values.[16] The weighted-mean bifurcation

---

[13] Schumm, op. cit., p. 603.

[14] Arthur N. Strahler, "Quantitative Geomorphology of Drainage Basins and Channel Networks," ed. Chow, Handbook of Applied Hydrology, Sec. 4-II (1964), p. 44.

[15] Ibid.

[16] Schumm, op. cit., p. 603.

ratio for the study area is 4.1 (Table 3). Bifurcation ratios characteristically range between 3 and 5 for watersheds in which the geologic structure does not distort the drainage pattern.[17] Hence, the bifurcation ratio of 4.1 for the study area conforms to theoretical values predicted on the basis of previous studies.

Bifurcation ratios are useful in predicting the character of maximum-flood discharges as well as being an expression of drainage basin geometry. Drainage basins with bifurcation ratios ranging between 2 and 5 tend to have a rotund shaped outline with the maximum-flood discharge coming as a sharp peak rather than a low and extended peak flow, which is characteristic of elongated drainage basins with higher bifurcation ratios.[18] The author, while working in the study area, observed that peak-flood discharge lasted only a short time (approximately 5 minutes) and came at the culmination of a brief thundershower which lasted about 30 minutes. Since the hydrological data necessary for constructing a hydrograph of basin discharge against time were not available, it is impossible to ascertain that basin discharge conforms to predicted behavior. Field observations do, however, support the postualte that maximum hydraulic discharge occurs during a short time span in the study area.

Stream Lengths

Stream lengths are dimensional properties that reveal the characteristic size of components of a drainage network. Horton postulated that the ratio of the mean stream-segment lengths of a given order to

---

[17] Strahler, "Quantitative Geomorphology of Drainage Basins and Channel Networks," op. cit., p. 45.

[18] Ibid.

TABLE 3

DERIVATION OF WEIGHTED-MEAN BIFURCATION RATIO

Stream Order	(1) Number of Streams	(2) Bifurcation Ratio	(3) Number of Streams Involved In Ratio	(4) Products of Columns (2) and (3)
1	61			
		3.812	77	293.5
2	16			
		5.333	19	105.3
3	3			
		3.000	4	12.0
4	1			
		Total	100	410.8

$$\frac{\leq \text{Bifurcation Ratio} \cdot \text{Number of Streams Involved}}{\leq \text{Number of Streams Involved in Ratio}} = \text{Weighted-mean Bifurcation Ratio}$$

$$\frac{410.8}{100} = 4.108$$

the mean length of the segments of the next lower order tend to be a constant throughout the successive orders of a drainage basin.[19] The weighted-mean of the stream-length ratio of the four stream orders in the study area is 1.4 (Table 4).

Assuming that the above law of stream lengths is valid, a graph of the logarithm of mean stream lengths plotted against their order number should yield a set of points lying approximately on a straight line. A number of studies have confirmed this law with data from many watersheds.[20] A graph of the stream length data from the study area may be observed in Figure 6. The stream length data representing the study area do not conform exactly to a direct geometric sequence but are closely clustered around the regression line $y = 0.328x + 1.87$ with a coefficient of correlation, $r = 0.923$.

Perhaps a reason why the data do not rigorously adhere to the stream length law is because geometric similarity is not preserved between tributary basins to the trunk stream of the study area. An observation of the base map (Figure 4) will reveal that the first and third order stream segments tend to be disproportionately more elongated than the second and fourth order stream segments.

---

[19] Horton, op. cit., p. 291.

[20] Schumm, op. cit., pp. 604-605; L. B. Leopold and J. P. Miller, Ephemeral Streams: Hydraulic Factors and Their Relation to the Drainage Net, United States Geological Survey Paper No. 282-A (Washington: United States Government Printing Office, 1956), p. 13; Marie E. Marisawa, Relation of Quantitative Geomorphology to the Stream Flow in Representative Watersheds of the Appalachian Plateau Province, Naval Research Project No. 389-042 (New York: Columbia University Department of Geology, 1959), pp. 48-50.

TABLE 4

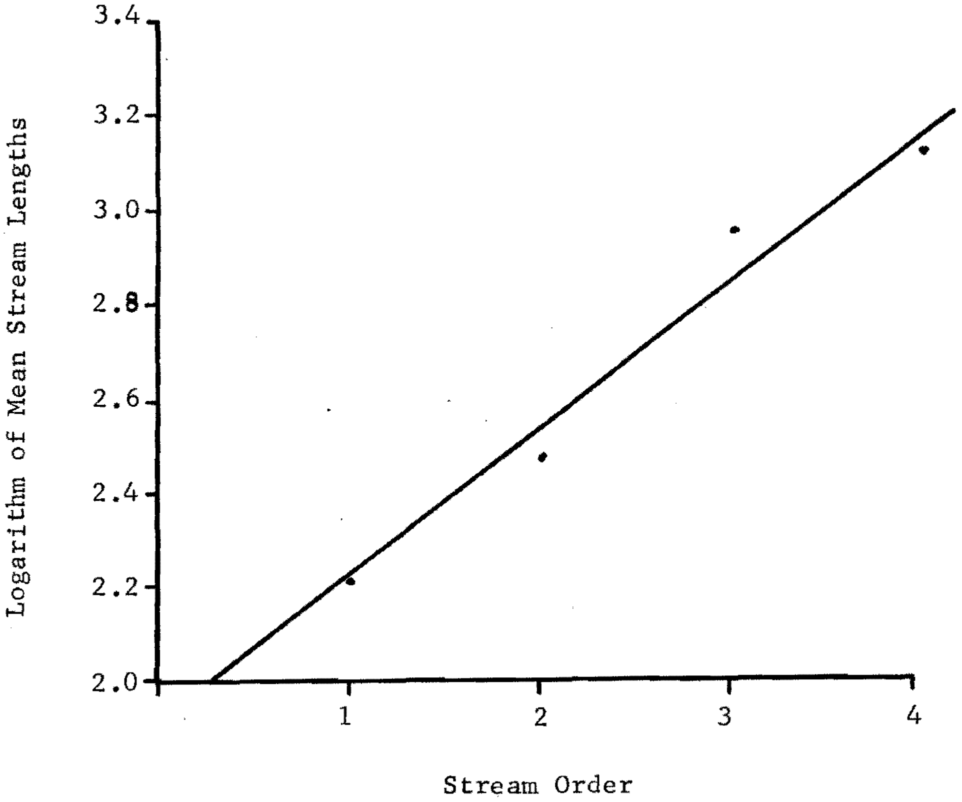
DERIVATION OF WEIGHTED-MEAN STREAM-LENGTH RATIO

Stream Order	(1) Mean Length In Feet	(2) Stream Length Ratio	(3) Total Mean Length Involved In Ratio	(4) Products of Columns (2) and (3)
1	167.6			
		1.74	459.8	800.05
2	292.2			
		.316	1212.2	384.64
3	925.0			
		1.84	2625.0	4830.00
4	1700.0			
		Total	4302.0	6014.69

$$\frac{\leq \text{Stream-Length Ratio} \cdot \text{Mean Length Involved}}{\leq \text{Mean Length Involved In Ratio}} = \text{Weighted-mean Stream Ratio}$$

$$\frac{6014.69}{4302.0} = 1.40$$

Stream Order	Mean Length of Streams in Feet	Logarithm of Mean Length of Streams
1	167.6	2.225
2	292.2	2.465
3	925.0	2.966
4	1700.0	3.123



Regression line equation: y = 0.328x + 1.87

Coefficient of correlation: r = 0.923

Fig. 6--Relation of logarithm of mean stream lengths to order numbers.

Length of Overland Flow

The length of overland flow has been defined as the length of flow path, projected to the horizontal, of non-channeled flow from a point on the drainage divide to a point on the adjacent stream channel.[21] The average length of overland flow for a particular drainage basin can be approximated by calculating one-half the reciprocal of the basin's drainage density.[22] The length of overland flow calculated for the study area is 105 feet. This distance, however, is not entirely non-channeled flow because numerous uncountable surface rills exist outside the mapped stream channels, especially on the exposed slopes. Nevertheless, it is valid to say that 105 feet is the mean length of flow outside first-order stream channels as they are defined in this paper. The overland flow length is especially important in the development of steep slopes along the high areas of the basin rim where sheetwash is a significant erosional process.

Areal Properties of the Drainage Basin

Basin Area Relationships

As mentioned earlier, the study area covers a planimetric area of 0.15 square miles. Each stream contained in the study area composes a secondary drainage basin of its own, thus partitioning the main drainage system into a series of smaller secondary drainage basins. The orderliness of these secondary basins was expressed by Schumm in the form of a law of basin areas: "The mean basin areas of streams of each order tend to approximate closely a direct geometric series in which the

---

[21] Horton, op. cit., p. 284.

[22] Ibid.

first term is the mean area of the first order basins."[23] Measured data from the study area conformed to the expected relationship (Figure 7) even though earlier observations showed that the streams composing the drainage basins did not exactly adhere to the prescribed laws. The above semmingly antagonistic relationships exist because second-order basins include the areas of all first-order basins which empty into them and third-order basins include the areas of all second and third order basins which empty into them and so forth; whereas, the cumulative stream lengths of a given order do not include the lengths of lower order streams. The orderly arrangement of the areal elements suggests that a regular symmetry exists between the secondary drainage basins within the study area independent of the fact that the length of stream segments composing them does not form an exact geometrical sequence.

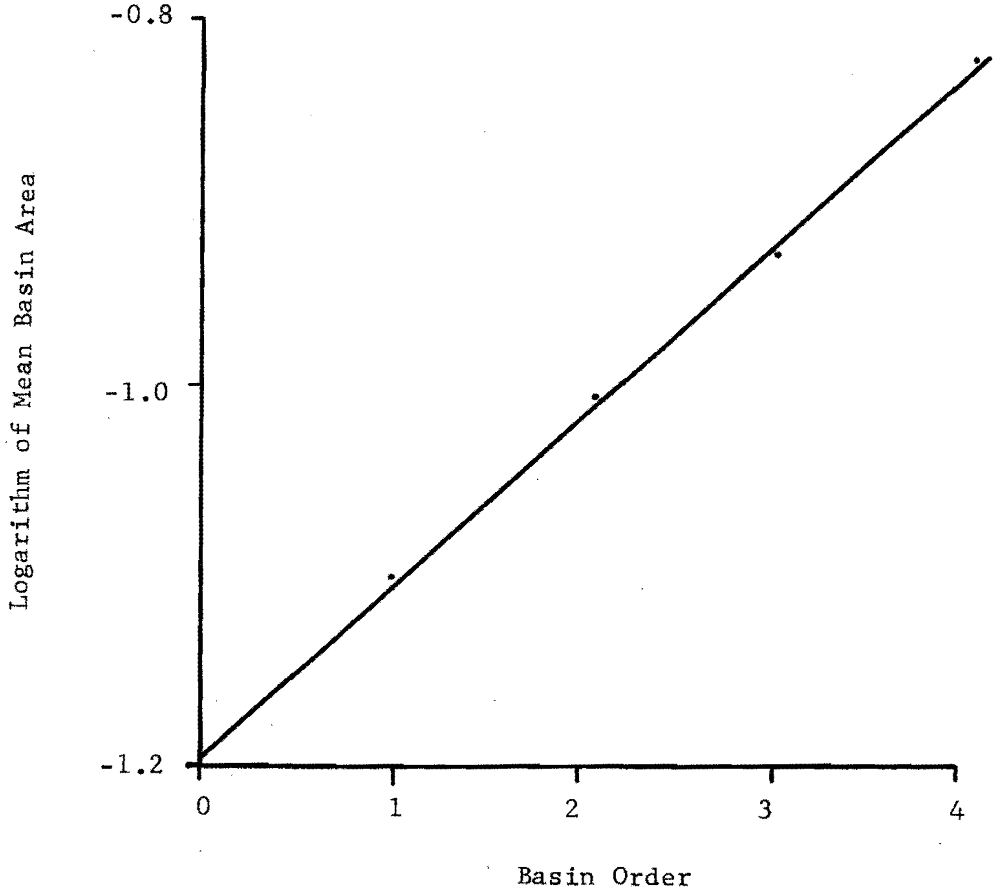
Basin-Area and Stream-Length Relationships

Under the assumption that the laws of stream lengths and basin areas are valid, it follows that the stream-length measurements should be related to the basin-area measurements. In the case of the study area, the form is the same as that of the stream-length and stream-order relationship (Figure 6) because the basin-area and basin-order relationship (Figure 7) forms a direct geometrical progression; whereas, the stream lengths only approximate the direct progression. A graph showing the relation of stream lengths to basin areas may be observed in Figure 8.

---

[23] Schumm, op. cit., p. 608.

Basin Order	Mean Basin Area in Square Miles	Logarithm of Mean Basin Area
1	.081	-1.0964
2	.10	-1.0000
3	.12	- .9271
4	.15	- .8239

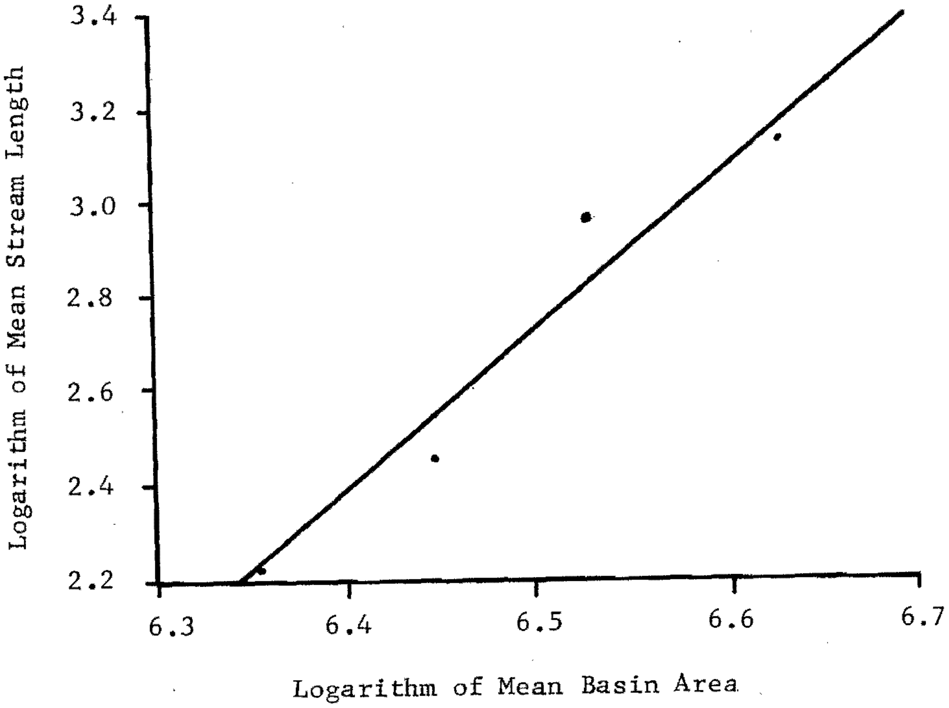


Regression line equation: $y = 0.0904x - 1.188$

Coefficient of correlation: $r = 0.949$

Fig. 7--Relation of mean area of secondary basins to basin order.

Order	Mean Length of Streams (Feet)	Mean Length of Streams (Logarithm)	Mean Basin Area (Square Feet)	Mean Basin Area (Logarithm)
1	167.6	2.225	2,258,150	6.3521
2	292.2	2.465	2,787,840	6.4440
3	925.0	2.966	3,345,408	6.5237
4	1700.0	3.123	4,181,760	6.6211



Regression line equation: $y = 0.292x + 5.699$

Coefficient of correlation: $r = 0.975$

Fig. 8--Relation between mean stream lengths and mean basin areas .

The significance of the stream-length and basin-area relationship is that the amount of mean square area which any specific length of stream channel drains may be predicted from the graph. Schumm defined a similar property which he termed "constant of channel maintenance." The constant of channel maintenance is the amount of mean square area necessary for the development of one foot of stream channel.[24] There are a number of ways in which the constant may be determined. It was determined for the study area as a ratio of total basin area to total stream length and found to be 215 square feet for each foot of stream length.

Basin Shape

The shape of a drainage basin is the geometrical form of its boundary when the basin is projected upon the horizontal datum plane of a map. The outline form of drainage basins has been described in a number of ways. Horton depicted the outline of a normal drainage basin as a pear-shaped ovoid and expressed it quantitatively as the ratio of basin area to the square of basin length.[25] Chorley, Malm, and Pogorzelski expressed the rotundity of basin shape as the degree of approach of its form to the pure lemniscate form which quantitatively is the ratio of the perimeter of the lemniscate to the actual perimeter of the basin.[26] A circularity ratio was defined by Miller as the ratio

---

[24] Ibid., p. 607.

[25] Horton, op. cit., pp. 303-304.

[26] J. R. Chorley, Donald E. G. Malm, and H. A. Pogorzelski, "A New Standard for Estimating Drainage Basin Shape," American Journal of Science, Volume 255, (1957), pp. 138-141.

of basin area to the area of a circle having the same perimeter as the basin. Schumm used an elongation ratio to express the shape of drainage basins, which is defined as the ratio of the diameter of a circle having the same area as the basin to the maximum basin length.[28] Morisawa analyzed the accuracy of the above methods by applying them to 25 watersheds in the Appalachian Plateau area. Her results showed a significant regression coefficient at the 5% level for only Schumm's and Miller's ratios which compare drainage basin shapes to circles.[29]

The basin shape of the study area was determined in accordance with Schumm's method and found to have an elongation ratio of 0.632. When elongation ratio values are near 1 they are associated with regions of very low relief; while values in the range of 0.6 and 0.8 are characteristic of regions with strong relief and steep slopes.[30] The ratio of 0.632, which describes the study area, is comparable to the elongation ratios of other badland areas. For example, the Perth Amboy, New Jersey, badland area has an elongation ratio of 0.602.[31]

Drainage Density and Stream Frequency

Drainage density is the ratio of the total cumulative length of stream channel segments for all orders within a given basin to the area of that basin. The drainage density of the study area was computed

---

[28] Schumm, op. cit., p. 612.

[29] Marie E. Morisawa, "Measurement of Drainage Basin Outline Form," Journal of Geology, Volume 66 (1958), pp. 587-591.

[30] Strahler, "Quantitative Geomorphology of Drainage Basins and Channel Networks," op. cit., p. 51.

[31] Schumm, op. cit., p. 612.

from the stream channels as they are shown on the base map (Figure 4) and determined to be 24.46 miles of stream channel per square mile. This value is significantly different from the 602 miles per square mile of drainage density that Schumm determined in the Perth Amboy badland area[32] and the 200 to 400 miles per square mile Smith measured in the Badlands National Monument, South Dakota.[33] It should be noted, however, that their studies were on plots much smaller in area than the basin being studied here; hence, their measurements included the numerous rill-like channels; whereas, this study includes only those stream channels identifiable from airphotos.

The stream frequency, which is the number of stream channel segments per unit area, is 540 streams per square mile for the study area. Both drainage density and stream frequency are a measure of the texture of a drainage network. The numbers alone, however, are not very useful without other values for comparison. Smith proposed a texture ratio which could be used to determine the class of topographic texture within a basin by comparing its ratio with given ratio values for different classes of topographic texture. He proposed as a texture ratio, the ratio of the number of crenulations on the contour having the maximum number of crenulations within a drainage basin to the length of the perimeter of the basin and established the following divisions for classes of topographic texture: (1) coarse texture has a ratio value below 4, (2) medium texture has ratio values ranging

---

[32] Ibid.

[33] Kenneth G. Smith, "Erosional Processes and Landforms in the Badlands National Monument," Bulletin Geological Society of America, Volume 69 (1958), p. 999.

from 4 to 10, and (3) fine textures include ratio values above 10.[34] The texture ratio for the study area was determined to be 18.2, making the basin's texture very fine, as might be expected in an extremely eroded badland area.

Relief Properties of the Study Area

Basin Gradient

The mean basin gradient measured along the major drainage channel of the study area is 8 feet per 100 feet. This is, however, an unrealistic and misleading function when applied to the entire study area since the longitudinal profile of any drainage basin consists of a series of connected segments from different stream orders. When the basin gradient was calculated for the first and second stream order portion of the basin apart from the third and fourth stream order portion, a significant difference in gradient was observed. The gradient of the first and second order portion was found to be 20 feet per 100 feet; whereas, the gradient of the third and fourth order portion was calculated to be 4.4 feet per 100 feet, thus facilitating a general upconcavity in basin profile.[35] A visual representation of the longitudinal profile of the study area and the proportion occupied by each stream order is indicated in Figure 9.

Gilbert explained the upconcavity effect as a result of increasing stream discharge because as discharge increases channel cross-section

---

[34] Kenneth G. Smith, "Standards for Grading Texture of Erosional Topography," American Journal of Science, Volume 248 (1950), pp. 655-668.

[35] The term upconcavity is used to indicate a persistant downstream decrease in gradient.

Distance From Head of Basin in Feet	Elevation in Feet
0	2560
200	2500
450	2440
800	2400
1385	2360
2260	2320
2860	2300
3500	2280

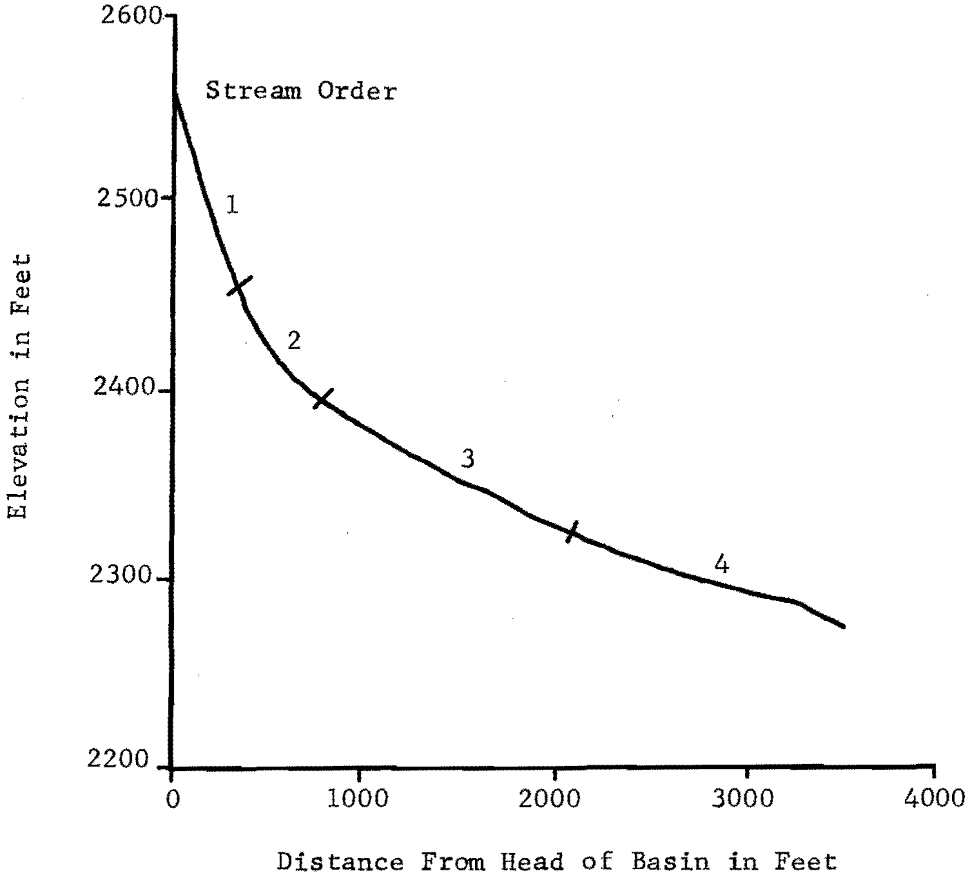


Fig. 9--Longitudinal profile of drainage basin.

also increases, thus, proportionately reducing the frictional losses of the stream and enabling it to carry its bedload on a lesser gradient.[36] Mackin later supported Gilbert by stating "each [stream] segment has the slope that will provide the velocity required for transportation of all of the load supplied to it from above, and this slope is maintained without change as long as controlling conditions remain the same."[37]

The study area conforms to Gilbert's theory in one respect; stream discharge does increase downstream with increasing stream order. However, the discharge increase within the study area does not seem to transport all the erosional material supplied to it from above; this is contrary to what both Gilbert and Mackin have implied regarding stream discharge. A map representing the characteristic surface material in the study area (Figure 15) shows that the area occupied by third and fourth order streams is composed of erosional fill. This fill is as much as 20 feet deep near the terminus of the drainage basin and is primarily responsible for the upconcavity of the study area profile. Ninety-five per cent of the drainage network within the study area is composed of first and second order stream segments with gradients similar to those represented in the longitudinal profile of the study area (Figure 9). Erosional debris from the soft Paleocene sediments is thus dumped into third and fourth order stream channels in such volumes that it is impossible for the hydrological discharge to transport them out of the basin. The overloaded stream

---

[36] G. K. Gilbert, Report on the Geology of the Henry Mountains, United States Geographical and Geological Survey of the Rocky Mountain Region (Washington: United States Government Printing Office, 1877), pp. 103-108.

[37] J. H. Mackin, "Concept of the Graded River," Bulletin Geological Society of America, Volume 59 (1948), p. 491.

deposits that part of its load which it cannot transport, and aggrades itself producing a concave profile such as that represented in the study area. The effect of channel filling in the area has been noted by Hamilton and related to change in precipitation and climate thought to occur in cycles over an extended period of years.[38]

Cross-section Basin Geometry

The use of transverse profiles is limited because accuracy of construction is inhibited by the presence of small gullies, crests, and spurs on the slopes. Consequently, the resulting form of a profile is dependent upon the angle at which the traverse intersects the small surface irregularities. Nevertheless, a generalized shape of the study area along the major drainage channel is represented in Figure 10 by transverse profiles across the midpoints of second, third, and fourth order stream channels. The profiles reveal the presence of steep slopes on both the north and south facing valley walls and show no distinct asymmetry within the basin.

The exposed south facing wall is more uniform and regular than the unexposed north facing wall. This is primarily because the north facing wall, having less exposure, retains enough moisture for the growth of vegetation which in turn enhances the further development of soil. When the moisture in the developed soil area reaches an optimum point, the soil is subjected to mass movements such as slumping and creep which create the hummocky, irregular surface represented in the cross-sections. On the other hand, the south facing slopes are exposed

---

[38] Thomas M. Hamilton, "Late-Recent Alluvium in Western North Dakota," Glacial Geology of the Missouri Coteau and Adjacent Areas, ed. Lee Clayton and Theodore F. Freers (Grand Forks: North Dakota Geological Survey, 1967), pp. 155-156.

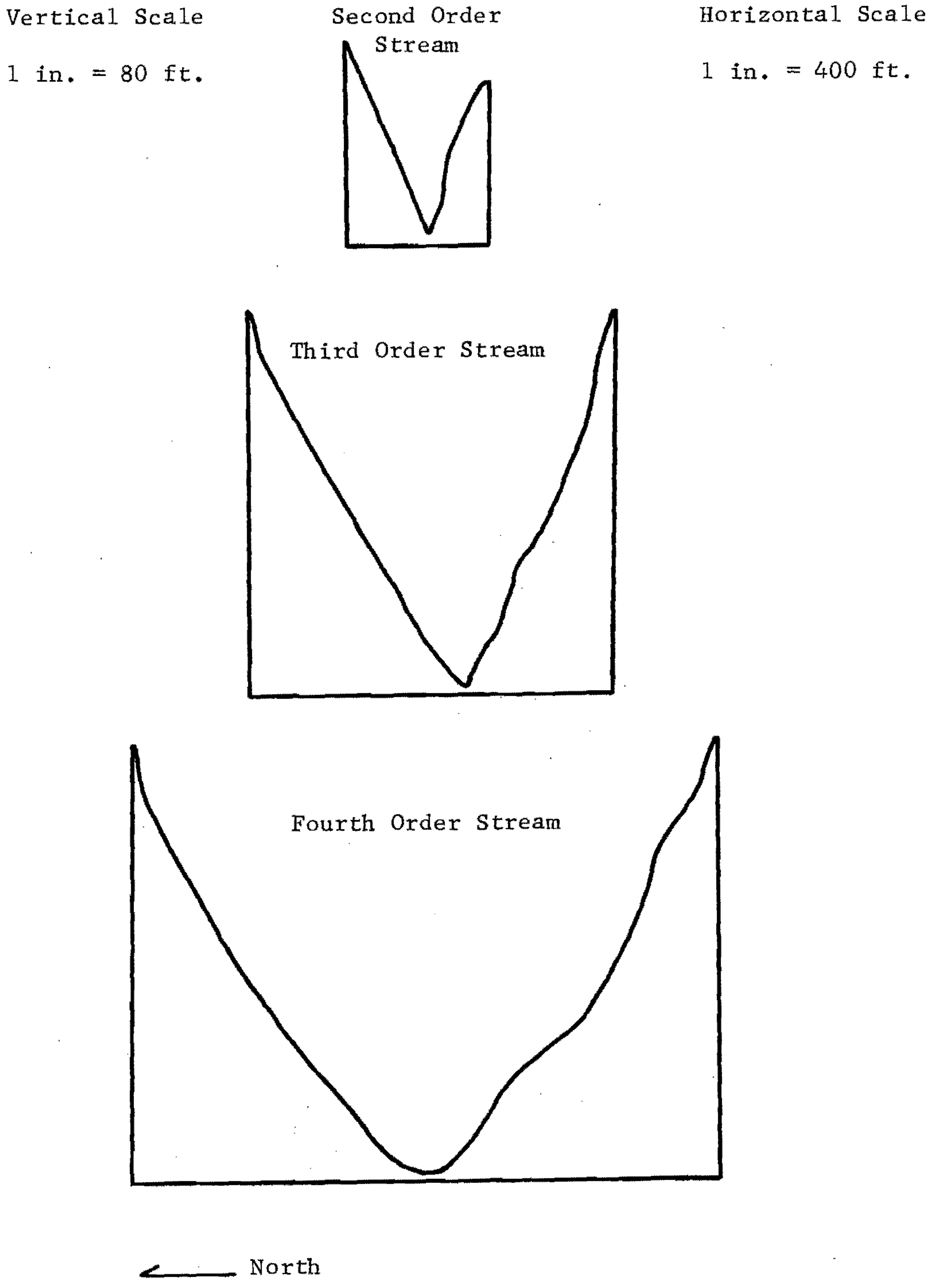


Fig. 10--Transverse profiles of study area.

to direct radiation and therefore lack a good vegetation cover or soil development. The surface is smoothly eroded by sheetwash and rill erosion into the long, straight, and steep walls as represented in the diagram.

Hypsometric Analysis

A hypsometric analysis is the relation of horizontal cross-section drainage-basin area to elevation. In general, it is a quantitative method for determining the erosional stage of development in a drainage basin. The method used to plot the hypsometric curve representing the study area (Figure 11) is best explained by Schumm:

> Data are obtained from the topographic map by measuring the total area of each basin with a planimeter, then measuring the area between each contour and the basin perimeter above it. Each area is converted into a percentage of total basin area so that a cumulative percentage curve can be plotted, each area value corresponding to a percentage of the total height of the basin. Using this hypsometric curve it is possible to read the percentage of total basin area above any percentage of total height.[39]

The area-altitude relationships within the drainage basin are consequently revealed by a curve illustrating in dimensionless coordinates the distribution of mass within the drainage basin.[40]

Three stages of erosion have been defined and related to the design of specific curves which result from the plotting of height ratios against area ratios; they are (1) the inequilibrium stage, (2) the equilibrium stage, and (3) the monadnock phase.[41] The curves

---

[39] Schumm, op. cit., p. 614.

[40] W. B. Langbin and others, Topographic Characteristics of Drainage Basins, United States Geological Survey, Water Survey Paper 968-C (Washington: United States Government Printing Office, 1947), p. 140.

[41] Strahler, "Hypsometric (Area-Altitude) Analysis of Erosional Topography," op. cit., pp. 1128-1132.

Percent of Area Above Given Percent of Elevation	Percent of Elevation
5%	73%
28%	60%
55%	40%
86%	20%
94%	6%
98%	2%

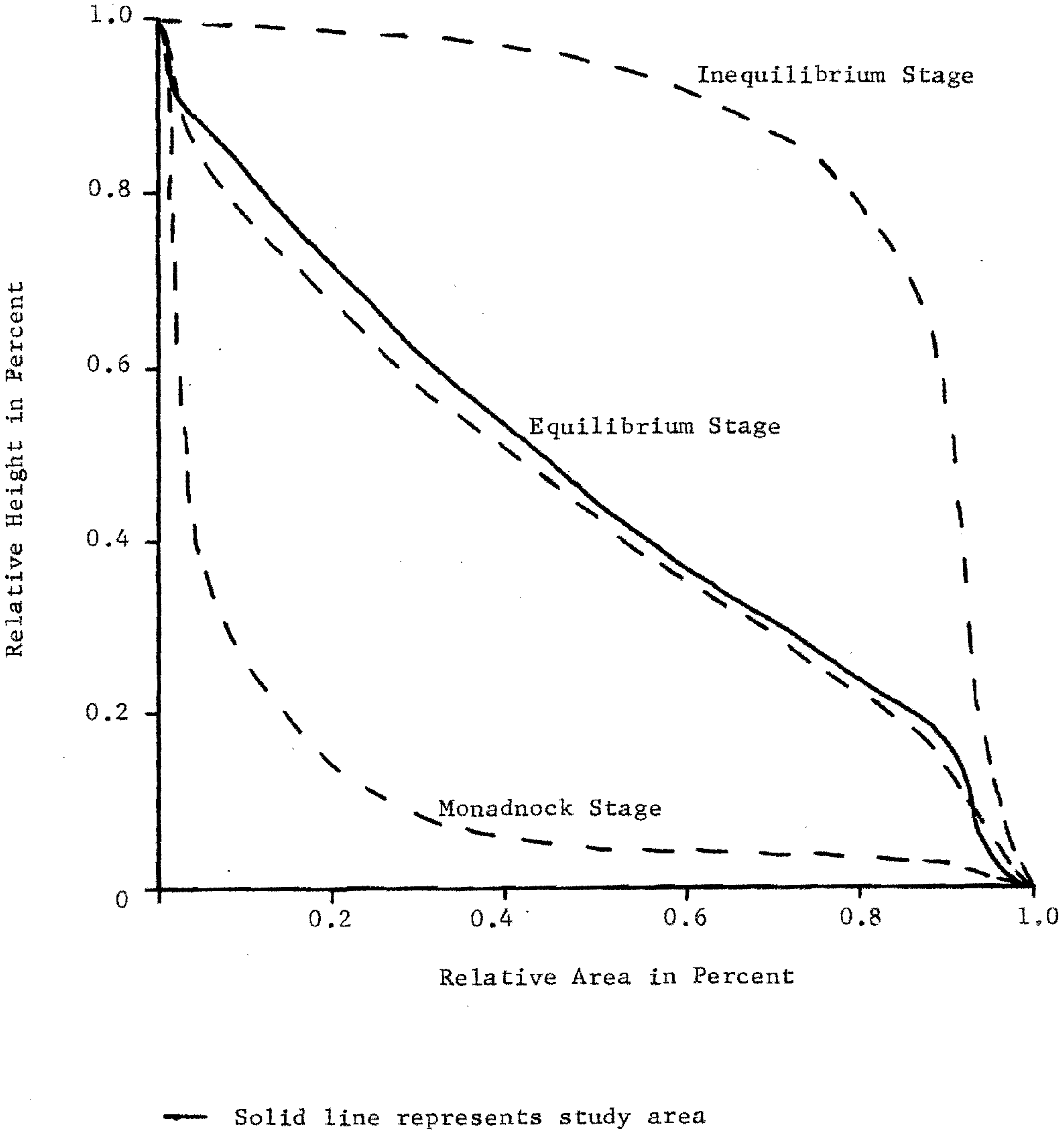


Fig. 11--Curve representing erosional stage of study area.

characteristic of each stage are depicted in Figure 11. Convex curves with a large percentage of their area in the higher elevations represent the youthful inequilibrium stage. The diagonal elongated "s-shaped" curve with approximately half of its area in high elevations and half in low elevations represents the mature equilibrium stage. The low concave curve with most of its area in the lower elevations represents the monadnock stage.

The solid curve of Figure 11, representing the stage of the study area, is typical of equilibrium forms. This means that the study area is primarily in slope and that geomorphic processes are in a steady state.[42] The fact that the basin is said to be in the equilibrium stage and therefore in a steady state does not mean that the area will remain constant without further down-wasting. On the contrary, the geomorphic processes constantly wearing away the study area will continue as long as there is no radical change in the present physical condition. It does mean, however, that the area should remain in slope and at approximately the same inclination as it approaches the monadnock stage.

---

[42] Ibid.

CHAPTER III

SURFACE ELEMENTS OF THE STUDY AREA

Cartographic Presentation and Compilation

Maps are used in this chapter to show the topographic distribution of each surface element discussed. The location of the various zones and classes of each element are represented by different shades of color superimposed over individual base maps showing the surface geometry of the drainage basin. Dashed boundaries are drawn between successively increasing or decreasing zones and classes to indicate a transition zone from one category to another rather than a sharp breaking point. Solid boundaries are used between the zones and classes which are not in successive order to indicate that a definite boundary exists between the two categories. The field measurements and values were recorded on a base map in the field and transmuted into maps of the different surface elements by drawing isolines between the values representing the different zones and classes. Airphoto stereopairs were used to help interpolate between known values and to establish the boundaries in areas between regular orthogonal lines where no measurements were available.

An interpreter of the maps may experience some confusion trying to establish a perspective with respect to relief since little elevation information is used. To alleviate this deficiency, symbols were used to represent high areas such as ridge crests and prominent escarpments;

whereas, stream-channel symbols were used to mark lower areas.

The maps are not without subjective considerations. However, there is some justification for the subjectivity involved because, as Calef and Newcomb have stated, "despite their appearance of more or less mathematical preciseness all maps designed to depict quantitative differences in terrain have a high degree of subjectivity."[43]

Ground Slopes of the Drainage Basin

Slope Zones

All landforms are composed of assemblages of individual slopes. Hence, it is difficult to accurately represent the slopes of landforms in their entirety because slope is an angular measurement of inclination of the ground surface at a specific point. Nevertheless, a quantitative and real expression of slope in a given area can be closely approximated by partitioning the various slope facets within an area into a number of discrete zones showing successive degrees of slope.[44] The location of the described slope zones within an area can then be expressed in the form of a slope-zone map and the slope measurements within each zone can be treated quantitatively.

Slope measurements were made in the study area using a regular sampling procedure and method previously described in the introduction. The measured data were partitioned into four categories which were delimited on the basis of four distinct slope facets found to exist within the drainage basin when a frequency distribution of the measured

---

[43] Wesley Calef and Robert Newcomb, "An Average Slope Map of Illinois," Annals, Association of American Geographers, Volume 43 (1953), p. 306.

[44] O. M. Miller and Charles H. Summerson, "Slope-Zone Maps," Geographical Review, Volume 50 (1960), p. 146.

slope values was plotted (Figure 12). The slope zones defined are:

1.	0° to 8°	the gently concave valley floor surfaces
2.	9° to 20°	smooth grass-covered slopes showing little evidence of mass movements
3.	21° to 40°	hummocky, unstable slopes with evidence of recent mass movements
4.	41° to 90°	slopes where intense erosion maintains steep, smooth surfaces

A map showing the surface distribution of these zones within the study area is presented in Figure 13.

Frequency Distribution of Slopes

The frequency distribution of slope is the proportion of the total surface falling within each slope zone into which the total angular range of slopes are subdivided.[45] The frequency distribution is found by measuring the total area each slope zone occupies and determining what percentage of total basin area each represents. A visual appraisal of the slopes in the study area may be gained from the frequency distribution histogram in Figure 14. The mean, variance, and standard deviation of the slope measurements from each zone are presented in Table 5.

The mean is a representation of the average value of slope within a given zone, the variance is the mean of the squares of deviations of measured slope values from the mean, and the standard deviation is the square root of the variance and a measure of the dispersion of measured slope values about the mean.

---

[45] Arthur N. Strahler, "Quantitative Slope Analysis," Bulletin Geological Society of America, Volume 67 (1956), p. 578.

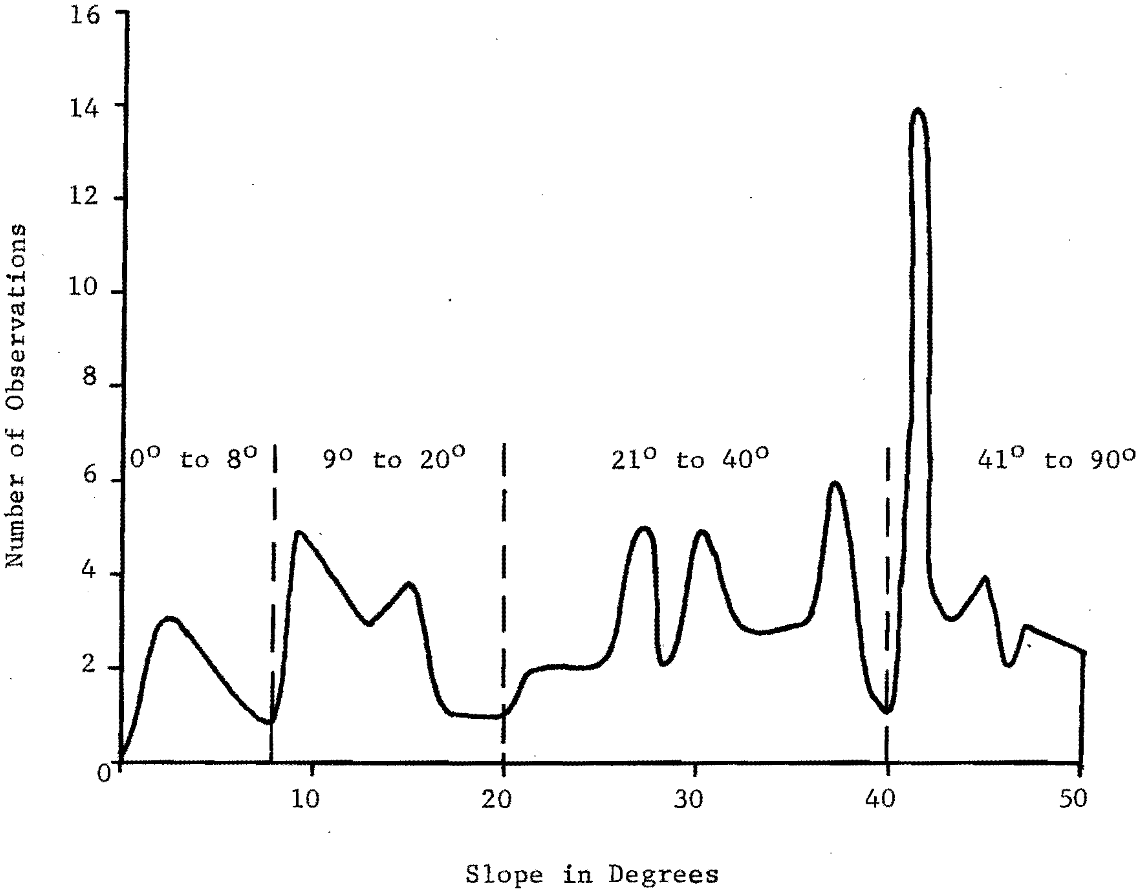


Fig. 12--Frequency distribution of slope measurements.

SLOPE ZONES

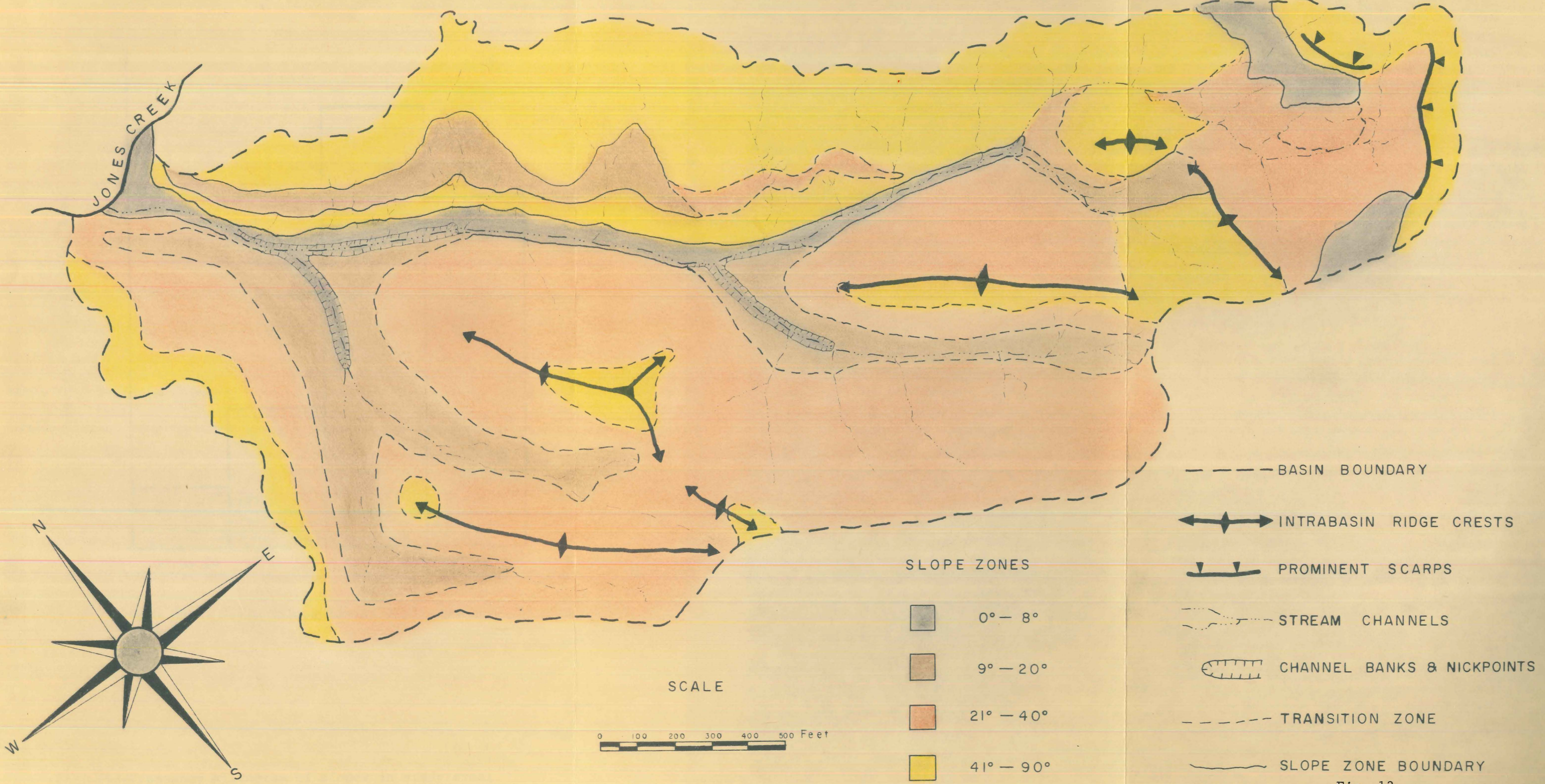


Fig. 13

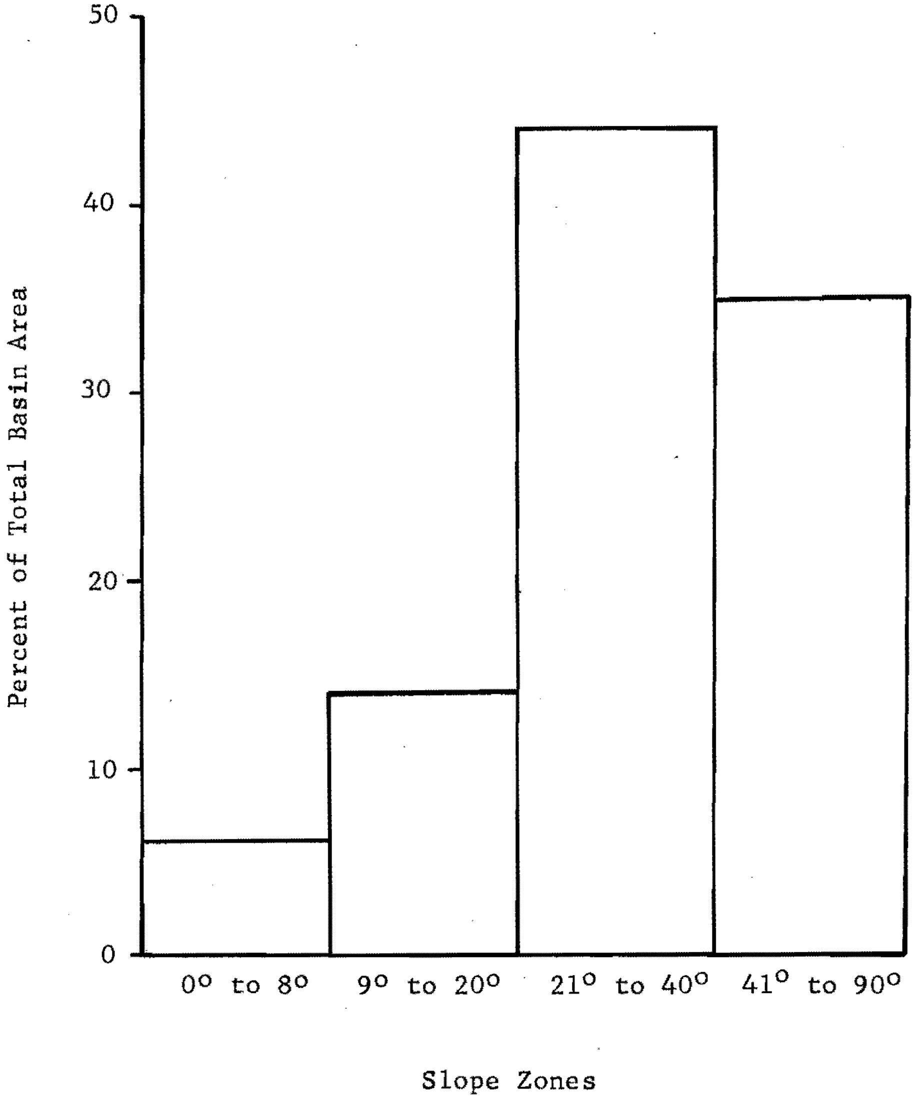


Fig. 14--Frequency histogram of slopes in study area.

TABLE 5

FUNDAMENTAL STATISTICS OF THE SLOPE ZONES

Slope Zones	Mean	Variance	Standard Deviation
0° to 8°	3.70°	3.21	1.792
9° to 20°	13.33°	11.31	3.363
21° to 40°	31.19°	26.16	5.115
41° to 90°	43.90°	10.26	3.205

Field Erosional Measurements

A series of erosional measurements were made to gain an idea of the intensity of erosional processes acting on the different slopes in the study area. The measurements were made on the exposed valley wall at approximately 5 foot intervals along an orthogonal line from basin rim to stream channel. The measurements were accomplished by a simple and inexpensive means using a method suggested by Emmett:

> A simple and proven way to measure rates of hill-slope erosion is to take a 10 inch nail (sometimes called a spike), slip the nail through a large washer, and drive the nail into the ground until the nail head and the washer are at the ground surface. Erosion undermines the washer which then falls down a length of the nail equal to the amount of erosion.[46]

Wooden stakes were also used. They were driven at a position 6 feet upstream from three small nickpoints near the basin terminus and along the top of a small slump scarp on the unexposed valley wall in the 21° to 40° slope zone. The measuring devices were established on April 1,

---

[46] William W. Emmett, The Vigil Network: Methods of Measurement and a Sampling of Data Collected, Extract of Publication No. 66, Symposium of Budapest (International Association of Scientific Hydrology, 1965), p. 98.

1967, and rechecked on June 11 and 12, 1967, when the author returned to the area for further field reconnaissance.

During the time span, April 1, 1967, to June 12, 1967, approximately 7 inches of precipitation fell in the southwest area of North Dakota.[47] During this time the mean erosion measured on the 41° to 90° slope zone was 0.15 inches, while the mean erosion measured on the 21° to 40° slope zone was 0.06 inches. No values were available for the 9° to 20° slope zone; however, 0.25 inches of accumulation was measured at one nail in the 0° to 8° slope zone. The wooden stakes recorded an upstream retreat of the three nickpoints from basin terminus of (1) 1.3 feet, (2) no measurable retreat, and (3) 3.2 feet, respectively. No change was noticeable around the slump scarp; however, the presence of numerous small recent scarps in the 21° to 40° zone indicates that mass movements are active in that zone. The hummocky topography caused by the mass movements is probably the reason for the larger standard deviation of slopes within the 21° to 40° zone.

There are a number of problems involved in attempting to measure erosion. For example, the washers around the nails tend to create a pedestal rather than falling down the nail after being undermined as Emmett suggested. Also, after prolonged periods of time the washers tend to corrode and form a rust bond with the nail. Finding the location of previously placed measuring devices can be a major problem if their locations are not properly recorded and marked; this is especially true when they are left unattended for extended periods of time. Also, if the area has freezing winter temperatures the spikes

---

[47] United States Department of Commerce, North Dakota Weekly Weather and Crop Report, Environmental Science Service Administration (Bismarck: Weather Bureau, April through June, 1967).

must be long enough to extend well below the freeze-thaw zone in order to avoid the effects of frost heaving. The wooden stakes used to measure nickpoint retreat were the more accurate of the devices used because nickpoint retreat was measured in feet rather than in tenths of inches. However, the accuracy of all the erosional measurements in this study could be questioned if they were to be used in calculating an erosional budget for the basin or establishing erosional rates. Nevertheless, they are useful in presenting an overall picture of the magnitude of the erosional processes shaping the slopes in the study area.

Surface Material of the Drainage Basin

Surface Material Classes

An expression of the surface material in an area is dependent upon the natural occurrence of surface material categories in that area. Once the basic elements have been differentiated, a refinement of detail can be carried to any desired degree and presented in a quantitative manner.[48] A topographic appraisal of the study area revealed the presence of three major types of surface material: areas of exposed bedrock, soil covered areas, and areas of alluvial fill. A more detailed reconnaissance of the study area revealed that a further division of the soil covered area would be useful in describing the surface materials present; hence, it was subdivided into two groups--poorly developed soils and well-developed soils. The final partition of the surface

---

[48] Edwin H. Hammond, "An Objective Approach to the Description of Terrain," Abstract-Annals, Association of American Geographers, Volume 44 (1954), p. 210. (Reference from mimeographed copy of complete text of paper, p. 3).

composition was into four classes which were differentiated and identified in the field on the basis of their content and physical appearance as previously described in the introduction. The four classes are:

1. Exposed bedrock	Found in areas of steep slopes, mostly within the 41° to 90° slope zone
2. Poorly developed soils	Found in areas where the slopes are gentle enough to allow the beginning of a soil mantle yet steep enough to inhibit their development, mostly within the 21° to 40° zone
3. Well-developed soils	Found in areas with slopes gentle and moist enough for a high degree of soil development, mostly in the 9° to 20° slope zone and on the unexposed valley wall
4. Alluvial fill	Found almost everywhere within the basin; however, the only significant accumulation is in the high order stream valleys, mostly in the 0° to 8° slope zone

A map showing the location of the various surface materials within the basin is presented in Figure 15. The map is subjective because field identification was made entirely from the qualitative attributes of the various surface material classes. Nevertheless, consistency of the observations make the map a representation of four given surface material classes within the study area.

SURFACE MATERIALS

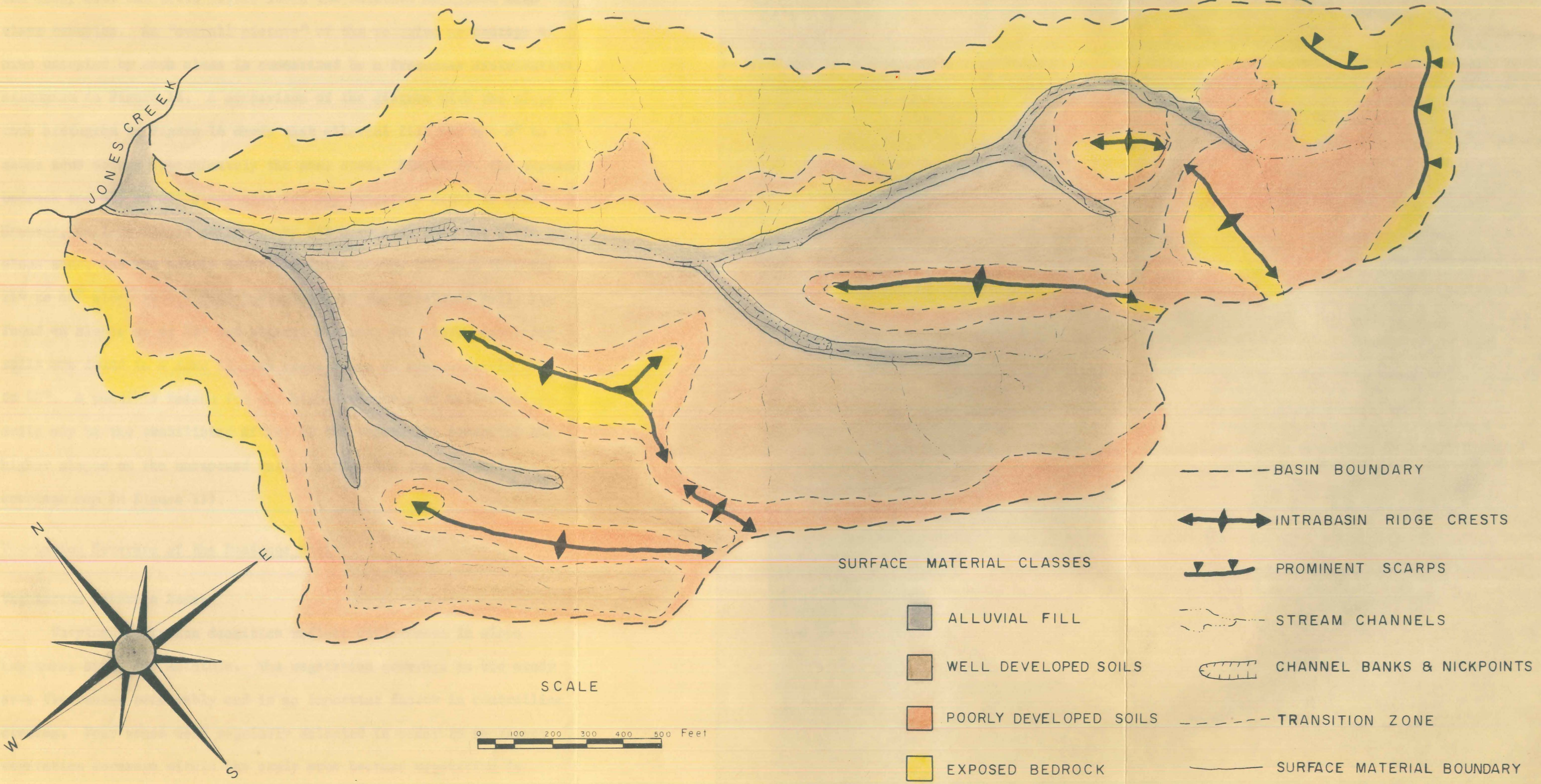


Fig. 15

Frequency Distribution of Surface Material

The areal distribution of the surface materials has been presented in map form. The map shows location of the surface materials within the study area but tells little about the relative magnitude each class occupies. An "overall picture" of the relative percentage of area occupied by each class is summarized by a frequency distribution histogram in Figure 16. A comparison of the diagram with the slope zone histogram in Figure 14 shows that alluvial fill and the 0° to 8° slope zone occupy approximately the same area. Similarly, the exposed bedrock and 41° to 90° slope zone are approximately equal in area. However, well-developed soils occupy 24% more area than the 9° to 20° slope zone, and the poorly developed soils occupy 20% less than the 21° to 40° slope zone. This indicates that the developed soils are found on slopes up to 25° and higher; whereas, the poorly developed soils are found in a more limited slope range of approximately 30° to 40°. A possible reason for the high percentage of well-developed soils may be the stabilizing effect of the vegetation occupying the higher slopes on the unexposed valley walls (See the vegetation coverage map in Figure 17).

Vegetation Coverage of the Drainage Basin

Vegetation Coverage Zones

Varying vegetation densities reflect differences in slope exposure, soil, and moisture. The vegetation coverage in the study area fluctuates seasonably and is an important factor in controlling erosion. Four zones were regularly selected in order to represent vegetation coverage within the study area because vegetation is

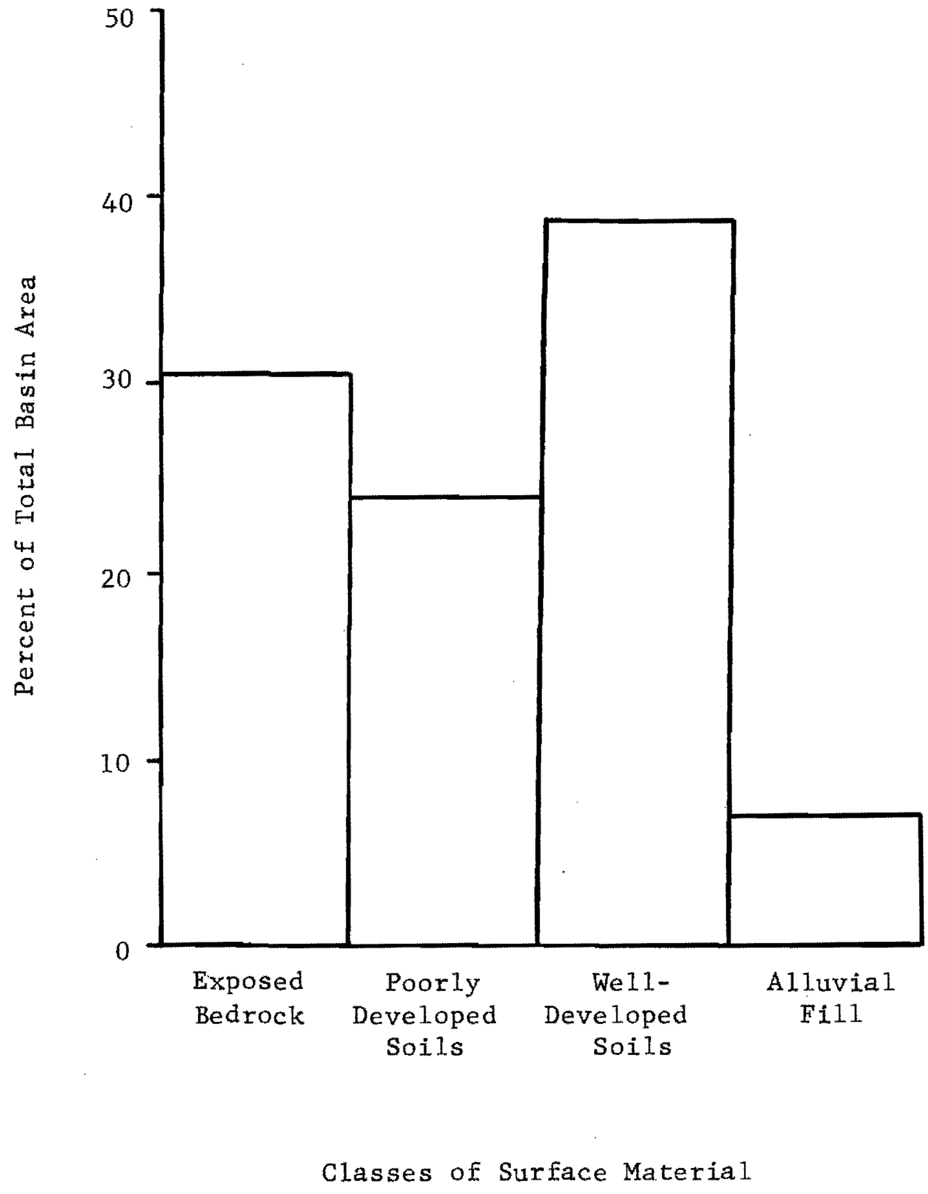


Fig. 16--Frequency distribution of surface material in the study area.

dependent upon numerous variables and there was no a priori basis upon which to define the vegetation coverage zones. The zones of coverage used in this study are:

1.	0 to 25%	Typical of exposed valley walls, exposed bedrock surfaces, and steep slopes, 41° to 90°
2.	26 to 50%	Typical of steep slopes, 30° to 50° on the unexposed valley wall where poorly developed soil is present
3.	51 to 75%	Typical of the 21° to 40° slope zone on the unexposed valley wall in the transition zones between well and poorly developed soils
4.	76 to 100%	Typical of well-developed soils in the 0° to 40° slope range on the unexposed valley wall

A map of vegetation coverage zones within the study area is presented in Figure 17. The fact that the field measurements used in drafting the map were made during the period of maximum vegetation coverage likely causes the map and frequency distribution to show a vegetation density somewhat higher than the mean annual coverage. As mentioned earlier, 50% of the moisture in the region occurs during May, June, and July, leaving the remainder of the year with little moisture in an already moisture deficient area.

Frequency Distribution of Vegetation Coverage

The frequency distribution of the vegetation coverage is represented by the histogram in Figure 18 and shows that the 76 to 100% category occupies the largest amount of area in the drainage basin. Although this is somewhat unexpected in badland topography, it is understandable because the well-developed soils occupy the greatest area of surface materials and the 21° to 40° slope zone occupies the

VEGETATION COVERAGE

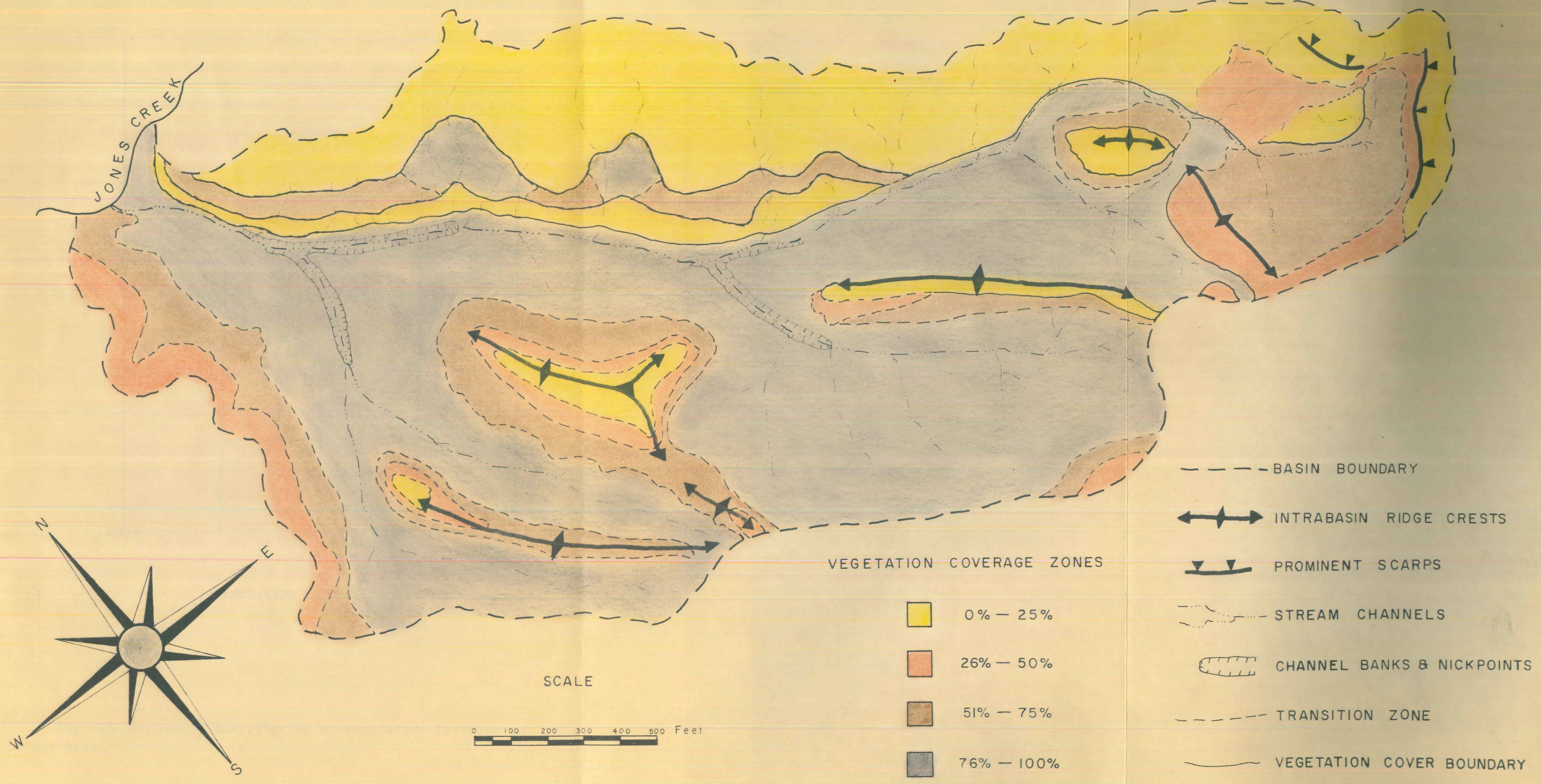


Fig. 17

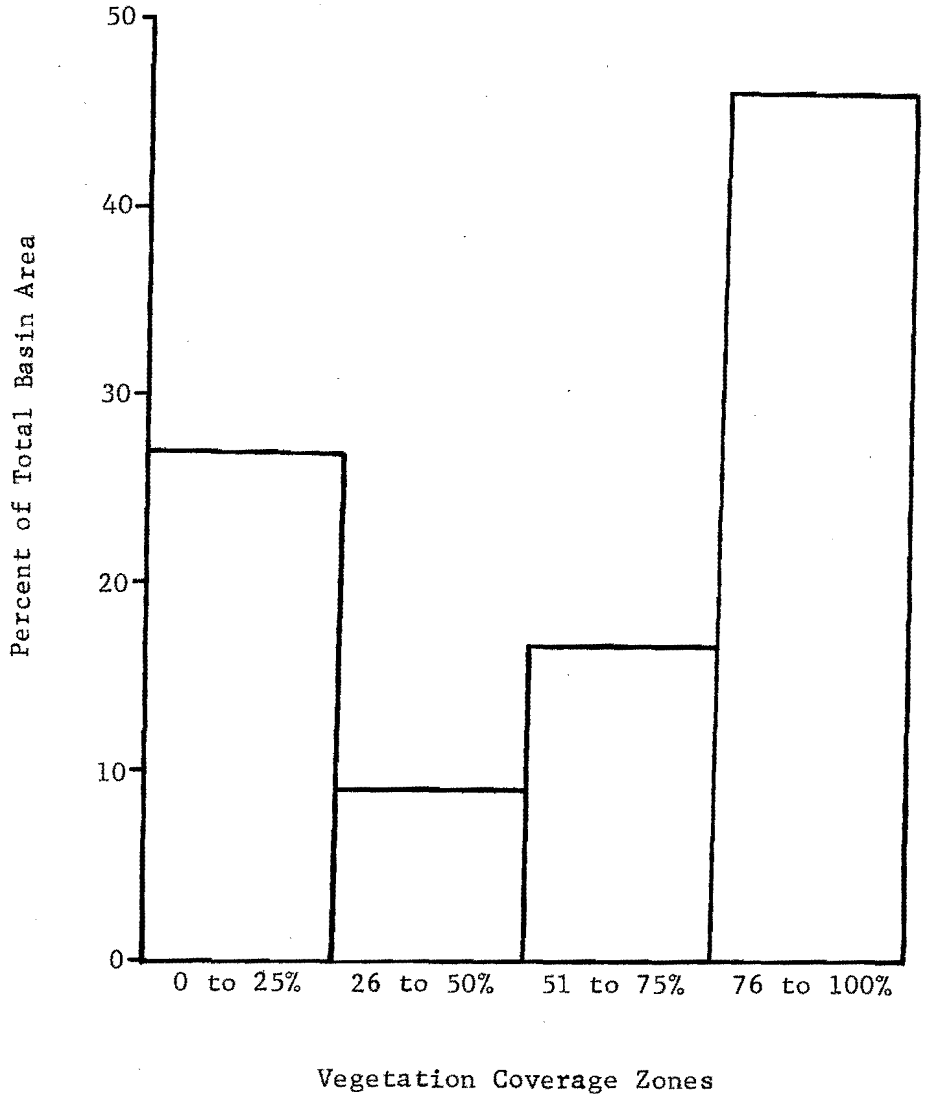


Fig. 18--Frequency distribution of vegetation coverage in study area.

greatest area of slope zones. The least vegetation-covered zone, 0 to 25%, is second in percentage of area occupied, with the 41° to 90° slope zones second in area coverage of slopes and exposed bedrock, second in surface-material coverage. The other categories do not show as high a degree of inter-relationship as those described above because different degrees of overlap occur between the individual zones and classes in the transition zones.

The mean, variance, and standard deviation of the individual vegetation coverage zones are given in Table 6.

TABLE 6

FUNDAMENTAL STATISTICS OF THE VEGETATION COVERAGE

Vegetation Coverage Zones	Mean	Variance	Standard Deviation
0 to 25%	13.80%	36.75	6.062
26 to 50%	33.33%	47.47	6.817
51 to 75%	68.33%	32.67	5.716
76 to 100%	92.55%	62.56	7.910

CHAPTER IV

SUMMARY AND CONCLUSIONS

The land surface configuration of a fourth-order drainage basin in the North Dakota Badlands has been described in its three dimensional form by considering its surface geometry, areal relationships, proportional relief, and surface elements. A combination of various known descriptive techniques and morphological laws were used to represent the raw landform as a functional and specific description of the surface form. As a result of the above procedures the following comments may be made about their application to the study area.

1. The drainage system generally conforms to prescribed laws of drainage composition. The minor deviations of the system from these laws can be explained in terms of geometric irregularities found to exist within the basin.

2. The bifurcation ratio of the study area characterizes the basin as being rotund shaped with maximum hydraulic discharge occurring in a short time span.

3. The amount of square area necessary for the maintenance of one foot of stream channel within the basin is 215 square feet and the amount of basin area drained by any specific length of stream channel is a function of the regression line equation $y = 0.292x + 5.699$.

4. The elongation ratio and texture indexes representing the study area are analogous to those determined for other badland areas

in comparative studies.

5. A hypsometric analysis of the study area's relief properties indicates that approximately one-half the original mass of the drainage basin has been removed by erosional processes and that the basin is presently in a stage of erosional equilibrium.

6. The surface elements of the study area appear to be dependent upon the location and frequency distribution of one another and appear to be directly affected by slope exposure to the sun's radiation.

This thesis is the only known study concerning a detailed morphological description of North Dakota Badland topography. It has shown some of the topographic aspects to be typical of other badland areas and some to be unique to the study area. It is believed that further investigation of the surface forms in drainage basins with different orientations and locations within the region would be fruitful. Such studies could be used to determine the topographic variation between locations and serve as representative areas for describing and mapping the surface elements of the entire badland area on a smaller scale. It is hoped that the information presented in this study can serve as an impetus and guide for continued studies and geographical understanding of the badland area in North Dakota.

APPENDIX

Statistical Formulae Used in the Tabulation and Presentation of Basic Data

The mean $= \frac{\Sigma X}{N}$

The variance $= \frac{\Sigma X^2}{N} - (\bar{X})^2$

Standard deviation $= \sqrt{\frac{X^2}{N} - (\bar{X})^2}$

Regression line $= \hat{Y} = \bar{Y} + b\,(X - \bar{X})$

Coefficient of correlation $= \frac{\text{Cov } XY}{\sigma X \cdot \sigma Y}$

where

X = an individual value or one of a series

ΣX = summation of all values under consideration

N = number of occurrences of X

$\bar{X}$ = mean of values for set of data

$\bar{Y}$ = mean of values for Y set of data

ΣXY = summation of the products of corresponding values of X and Y set of data

ΣX^2 = summation of the squares of each X value

$\hat{Y}$ = predicted value of Y when given a value for X

σX = standard deviation for X set of values

σY = standard deviation for Y set of values

Cov $XY = \frac{\Sigma XY}{N} - \bar{X} \cdot \bar{Y}$

$b = \frac{\text{Cov } XY}{\text{Variance of } X \text{ set of data}}$

BIBLIOGRAPHY

Public Documents

North Dakota Economic Development Commission. A Combination of Facts About North Dakota. Compiled by David R. Torkelson. Bismarck: North Dakota Economic Development Commission, 1964.

United States Department of Commerce. Climatography of the United States, Nos. 11-28 and 86-26. Washington: United States Government Printing Office, 1931-1960.

United States Department of Commerce. North Dakota Weekly Weather and Crop Report. Environmental Science Service Administration. Bismarck: Weather Bureau, April through June, 1967.

Books

Stevens, Orin A. Handbook of North Dakota Plants. Fargo: Knight Printing Company, 1950.

Articles and Periodicals

Calef, Wesley and Newcomb, Robert. "An Average Slope Map of Illinois," Annals, Association of American Geographers, Vol. 43 (1953), pp. 305-316.

Chorley, J., Malm, D. E. G., and Pogorzelski, H. A. "A New Standard for Estimating Drainage Basin Shape," American Journal of Science, Vol. 255 (1957), pp. 138-141.

Hamilton, Thomas M. "Late-Recent Alluvium in Western North Dakota," Glacial Geology of the Missouri Coteau and Adjacent Areas, ed. Lee Clayton and Theodore F. Freers, Grand Forks: North Dakota Geological Survey, 1967.

Hammond, Edwin H. "An Objective Approach to the Description of Terrain," Abstract, Annals, Association of American Geographers, Vol. 44 (1954), p. 210. (Mimeographed copy of complete text was used.)

Horton, Robert E. "Erosional Development of Streams and Their Drainage Basins: Hydrophysical Approach to Quantitative Morphology," Bulletin, Geological Society of America, Vol. 56 (1954), pp. 275-370.

Macking, J. H. "Concept of the Graded River," *Bulletin, Geological Society of America*, Vol. 59 (1948), pp. 463-512.

Miller, O. M. and Summerson, Charles H. "Slope-Zone Maps," *Geographical Review*, Vol. 50 (1960), pp. 194-202.

Morisawa, Marie E. "Measurement of Drainage Basin Outline Form," *Journal of Geology*, Vol. 66 (1958), pp. 587-591.

Schumm, Stanley A. "Evolution of Drainage Systems and Slopes in Badlands at Perth Amboy, New Jersey," *Bulletin, Geological Society of America*, Vol. 67 (1956), pp. 597-646.

Smith, Kenneth G. "Standards for Grading Texture of Erosional Topography," *American Journal of Science*, Vol. 248 (1950), pp. 655-668.

_______. "Erosional Processes and Landforms in the Badlands National Monument," *Bulletin, Geological Society of America*, Vol. 69 (1958), pp. 975-1008.

Strahler, Arthur N. "Hypsometric (Area-Altitude) Analysis of Erosional Topography," *Bulletin, Geological Society of America*, Vol. 20 (1952), pp. 1117-1142.

_______. "Quantitative Geomorphology of Drainage Basins and Channel Networks," Ed. Chow, *Handbook of Applied Hydrology*, Sec. 4-II (1964), pp. 39-76.

_______. "Quantitative Slope Analysis," *Bulletin, Geological Society of America*, Vol. 67 (1956), pp. 571-576.

Woodruff, James F. and Evenden, Leonard J. "Geomorphic Measurements from Air Photos," *The Professional Geographer*, Vol. XIV (1962), pp. 23-26.

Reports

Emmett, William W. *The Vigil Network: Method of Measurement and a Sampling of Data Collected*. Extract of Publication No. 66, Symposium of Budapest, International Association of Scientific Hydrology, 1965.

Gilbert, G. K. *Report on the Geology of the Henry Mountains*. United States Geographical and Geological Survey of the Rocky Mountain Region, Washington: United States Government Printing Office, 1877.

Laird, Wilson M. *The Geology of the South Unit Theodore Roosevelt National Memorial Park*. Grand Forks: North Dakota Geological Survey Bulletin No. 25, 1950.

Langbin, W. B. and others. *Topographic Characteristics of Drainage Basins*. United States Geological Survey, Water-Survey Paper 968-C, Washington: United States Government Printing Office, 1947.

Leopold, L. B. and Miller, J. P. *Ephemeral Streams: Hydraulic Factors and Their Relation to the Drainage Net*. United States Geological Survey Paper No. 282-A, Washington: United States Government Printing Office, 1956.

Miller, V. C. *A Quantitative Geomorphic Study of Drainage Basin Characteristics in the Clinch Mountain Area, Virginia and Tennessee*. Naval Research Project 389-042, Technical Report No. 3, New York: Columbia University, Department of Geology, 1953.

Morisawa, Marie E. *Relation of Quantitative Geomorphology to Stream Flow in Representative Watersheds of the Appalachian Plateau Province*. Naval Research Project No. 389-042, Technical Report No. 20, New York: Columbia University, Department of Geology, 1959.

Unpublished Material

Hamilton, Thomas M. "Recent Fluvial Geology in Western North Dakota." Unpublished Master's Thesis, Department of Geology, University of North Dakota, 1967.